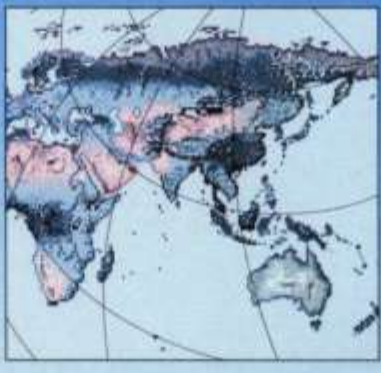
tsunami

PNG 1998

extracts from Earth Talk



By Prof Hugh Davies

Cover

The photograph of survivors is by Patrick Hamilton of The Australian newspaper, Sydney. The photograph of leaning house posts in the former Warapu village is by the author.

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Tsunami PNG 1998
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The great tsunami

On the evening of Friday 17 July 1998 a powerful tsunami struck the north coast of the island of New Guinea just west ofAitape. The wave completely destroyed three densely populated villages that were located on the sandbar that fringes Sissano Lagoon, destroyed most of a fourth village further west, and swept away the grand church at Sissano mission that had stood for more than 70 years. The wave also damaged villages along the coast east of the lagoon as far as Aitape and the mouth of the Raihu River.

Rescue efforts commenced on Saturday morning and accelerated through the following days. Hospitals at Wewak, Aitape and Vanimo and an Australian Defence Force temporary field hospital at Vanimo overflowed with the injured. The disaster attracted worldwide media attention and drew a generous response from donors within country and overseas.

In all, 2202 people lost their lives and 1000 were treated for injuries; many of those who died were the aged and the very young. A total of 10 000 survivors lost their homes and personal possessions and required immediate relief food supplies and temporary accommodation in care centres.

For the survivors there was grief at the loss of loved ones, confusion, rumour and the fear that another tsunami would strike. Grief counsellors were quickly on the scene and their work continues unabated today. I was drawn into the scene to provide reliable information to those who survived, and to other coast dwellers. This book grew from that public information program and, indeed, is a continuation of it.

By April 1999 all those displaced by the wave were in the process of making a fresh start in the new resettlement villages at some distance from the coast. Schools, churches and aid posts that were destroyed by the wave were being re-built in the new locations, and distribution of relief food had ceased.

The recovery was made possible by the generous contributions of cash and kind by donors in country and overseas, by the effort of many volunteers, and by a team of dedicated people including the staff of the National Disaster and Emergency Services; the Assistant Controllers at Aitape during the emergency, Geoffrey Baki and Vincent Tutu, and the administrative staff at Aitape; Balthazar Maketu and staff at the Rehabilitation Centre, Catholic Diocese of Aitape; and the NGOs.

This book is dedicated to the memory of those who lost their lives, and as a tribute to the courage and resilience of the survivors. I also hope it will be accepted as a tribute by the many selfless people who have given and continue to give care and help where needed. For all of us, the stories in these pages should serve as a reminder of the risk that tsunamis pose to all coastal communities, and should be a stimulus for us to plan and prepare with this risk in mind.

Hugh Davies
University of Papua New Guinea
25 November 1998; 7 May 1999

Earth Talk appeared weekly in the ***The National*** newspaper in 1998. The column dealt with issues of concern to us here in Papua New Guinea such as earthquakes, volcanoes, climate change and, more recently, tsunamis. The tsunami columns are brought together here. Errors have been corrected in some, and illustrations added. For technical advice about tsunamis I thank members of the international tsunami science community, particularly Professors Costas Synolakis, U.S.A, and Fumihiko Imamura, Japan. For Tok Pisin translation I thank Dicks Thomas of UPNG. Any earnings from the sale of this book will be directed into further tsunami research and awareness in Papua New Guinea.

What is a tsunami?

Earth Talk for 22 July 1998

A tsunami or seismic sea wave is a repeated rising and falling of the sea surface caused by any major disturbance on the sea floor, such as a large earthquake, submarine landslide or volcanic eruption.

The effect is rather like what we see if a pebble is thrown into a pond of water. The pebble displaces water and small waves radiate in all directions from the point of impact..

Where the seismic sea wave reaches the shore it may cause a simple rising and falling of sea level if the shoreline is steep, or a breaking wave if the shoreline has a gentle slope.

The word tsunami is from the Japanese “tsu” for harbour and “nami” for wave, so named no doubt because it is an ocean wave that can affect even the most secure harbour.

Tsunamis are common in our region because of the prevalence of earthquake and volcanic activity in the Pacific Ring of Fire. However, most are of moderate scale with fluctuations in sea level of less than two metres. These are termed Magnitude 1 events and cause little damage.

The most severe tsunamis ever recorded are Magnitude 4 and have a maximum height of 30 m. Such major tsunamis were generated by the eruption and collapse of Krakatau volcano in Indonesia in 1883 and caused more than 36 000 deaths.

There have been 50 tsunamis in PNG waters in the last hundred years, including moderate events that preceded the eruptions of Rabaul volcano in 1937 and 1994. The most severe in our history was in 1888 and was caused by the collapse of Ritter Island volcano.

Ritter Island lies just west of the western tip of New Britain. The collapse of one flank of the volcano generated a seismic sea wave up to 12 m high that caused great devastation and loss of life along the New Britain coast and the Siassi Islands and also affected the Huon Peninsula and Rai coast.

The tsunami that struck the Aitape coastline on Friday had a maximum height of 10-15 metres and was thus a Magnitude 3 event. Such events can be expected to cause damage along as much as 400 km of coastline.

The tsunami followed soon after a magnitude 7 earthquake and was generated by a disturbance on the sea floor associated with the earthquake. The movement could have been a displacement of the sea floor by movement on a fault.

Alternatively the tsunami may have been caused by a major submarine landslide or gas-driven mud volcano, triggered by the earthquake .The sea floor off Aitape has a steep slope and sediments that have accumulated on this slope would be readily destabilised by a major earthquake.

Tsunami preparedness

If a tsunami is generated by a distant earthquake it is possible to issue warnings. This is the task of the Tsunami Warning Centre in Hawaii.

For example, at the time of the 1964 earthquake in Anchorage, Alaska, tsunami warnings were issued for the west coast of North America. Significant damage was caused by a tsunami at Crescent City in northern California, almost 2000 km distant, but because of the warning there was no loss of life.

In the San Francisco Bay area on the other hand the warning had the opposite effect. Thrillseekers assembled on the shoreline to see the sea wave arrive. Fortunately for them the sea wave had dissipated into a minor ripple at this point.)

If a tsunami is generated by a nearby earthquake then there is no time to give a warning because the sea wave will follow soon after the earthquake.

In this situation, all that one can say by way of advice is that if you live near sea level and feel a strong earthquake, see any unusual change in the level of the sea, or hear a roaring noise then be aware that a tsunami may be on the way and move quickly to higher ground.

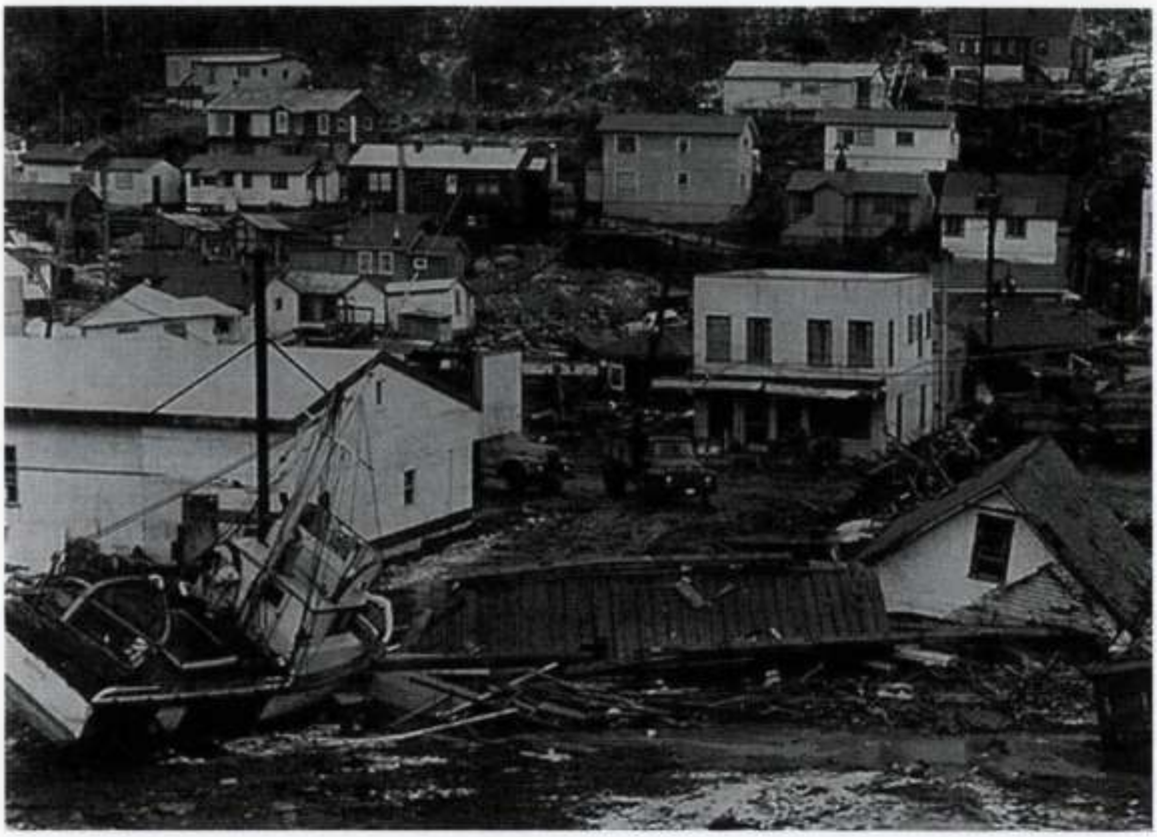
In the 1970s, the late Ian Everingham developed a catalogue of tsunamis that had occurred in the New Guinea and Solomons region. Ian was concerned to promote community awareness of the risk posed by tsunamis.

Over the succeeding years we have become less aware of this risk. This is because major tsunamis are relatively rare events. For example there have been only two or three magnitude 3 events in PNG waters in 110 years. Recollections of the last major tsunami pass from living memory before the next occurs.

Tsunami warning signs -

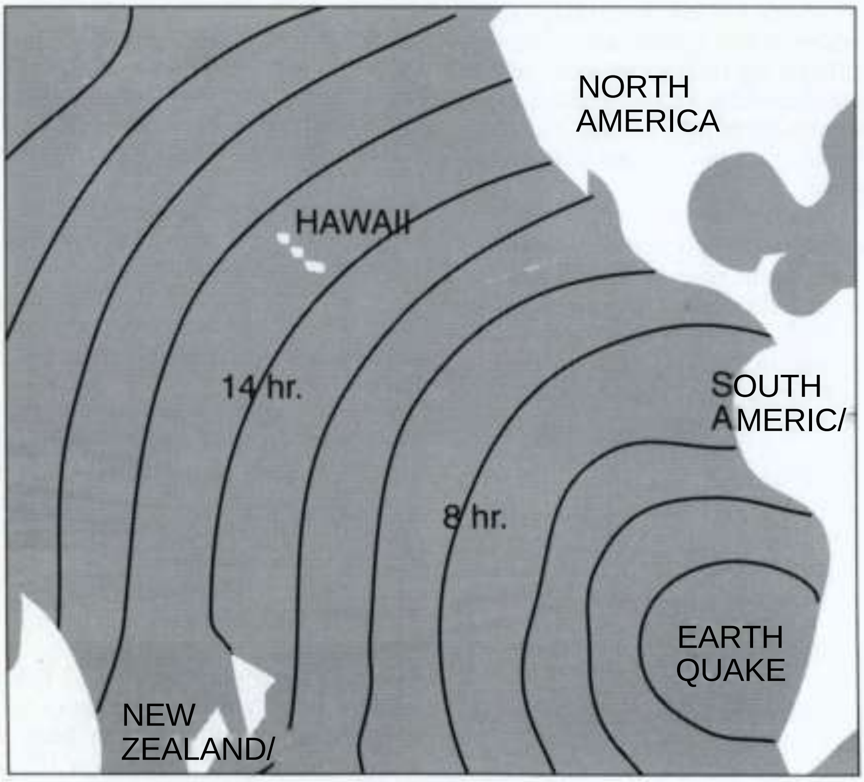
- a strong earthquake
- an unusual change in the level of the sea
- a roaring noise

If you are on the coast and become aware of any of the warning signs, move quickly away from the water’s edge and to higher ground.



ABOVE: A tsunami in Kodiak, Alaska, in March 1964 caused 21 deaths and K60 million damage.

BELOW: Calculated travel times for a tsunami caused by an earthquake occurring near the coast of Chile.
Illustrations courtesy of the International Tsunami Information Center, Honolulu.



What caused the tsunami?

Earth Talk for 28 July 1998

On the evening of Friday, July 17 at about 7.10pm a breaking wave from a massive tsunami swept across the sand bar that forms the outer margin of Sissano Lagoon.

The terrible destruction and loss of life that ensued is now a part of our history and of the consciousness of all of us. No-one who has heard the radio accounts, read the newspapers, or seen the TVcoverage can have remained untouched by this, the worst disaster in the modem history of our islands.

The purpose of today's Earth Talk is to start piecing together the physical details of the event.

What exactly happened and when? Why did it happen? And could it happen again? Let me say at the start that I don't have all the answers. If readers can help fill in the gaps, please contact me at e-mail hdavies@upng.ac.pg or fax 3260369.

So, what happened and when?

First the earthquakes. According our friends at the Port Moresby Geophysical Observatory, there were two strong earthquakes on that Friday evening, one at 6.49 pm and the other at 7.09pm.

The first had a magnitude of 7.0 and the second earthquake was near 7.0, possibly slightly stronger.

Overseas observatories located the earthquake as offshore somewhere within 100 km of Aitape (see map). It was difficult for them to be more precise than that because there were no earthquake recording stations close to Aitape. The nearest recording station was at Wewak and this was not triggered by the first earthquake.

The earthquakes were strongly felt and continued for several minutes. Some described a sharp up-an-down motion beneath their feet, followed by a sideways motion. People ran from their houses and checked for damage or watched with concern as cracks opened in the ground and water bubbled up in the cracks and around house posts.

The first earthquake was followed after an interval of 15-20 minutes by a towering tsunami.

Villagers interviewed on television recounted hearing a sound like the roar of a jet engine. When they looked out to sea it was as though a wall of water were moving towards them.

The wave broke with tremendous force and surged across the sandbar carrying almost all before it.

I won't try to describe this scene because it has been well covered in the media, except to note that the force of the water was sufficient to carry away strongly built houses and to wrap pieces of sheet metal around the trunks of coconut palms.

The giant sea surge was preceded by a fall in sea level.

Our student at Aitape described how, before the arrival of the tsunami, the sea level dropped and the sea receded a great distance. An initial fall in sea level has been a feature of all previous PNG tsunamis.

Now let's move on to the cause of the tsunami.

According to earthquake research experts in Tokyo, the tsunami probably was caused by abrupt movement on a fault that displaced the sea floor. Their modelling showed that two metres of vertical displacement of the seabed along a fault 18km long would be required.

For the time being we can accept this as the most likely cause of the tsunami. Movement on a fault at a point offshore from Sissano and at a depth of some kilometres below the sea floor caused a magnitude 7.0 earthquake.

The same movement caused a rupturing of the sea floor along the surface trace of the fault. The movement of the sea floor, in turn, displaced a large volume of sea water and thus produced a tsunami.

The story will doubtless be refined over the coming weeks as more data are assembled.

We can ask why there was a delay of 20-30 minutes between the earthquake and the arrival of the tsunami. From my admittedly very limited knowledge of tsunamis, I would have thought the tsunami should follow within minutes of the earthquake.

An alternative explanation is that the tsunami was caused by a major submarine landslide. The seabed offshore from Sissano falls away to a trench that is about 3.5 km deep. As the illustration shows, the inner slope of the trench up to the coast at Sissano, is relatively steep and is broken by a number of faults.

The earthquake would tend to destabilise unconsolidated sediments on the upper part of the slope offshore from Sissano and could cause them to slump seawards. If the slump were on a large enough scale it would cause a tsunami.

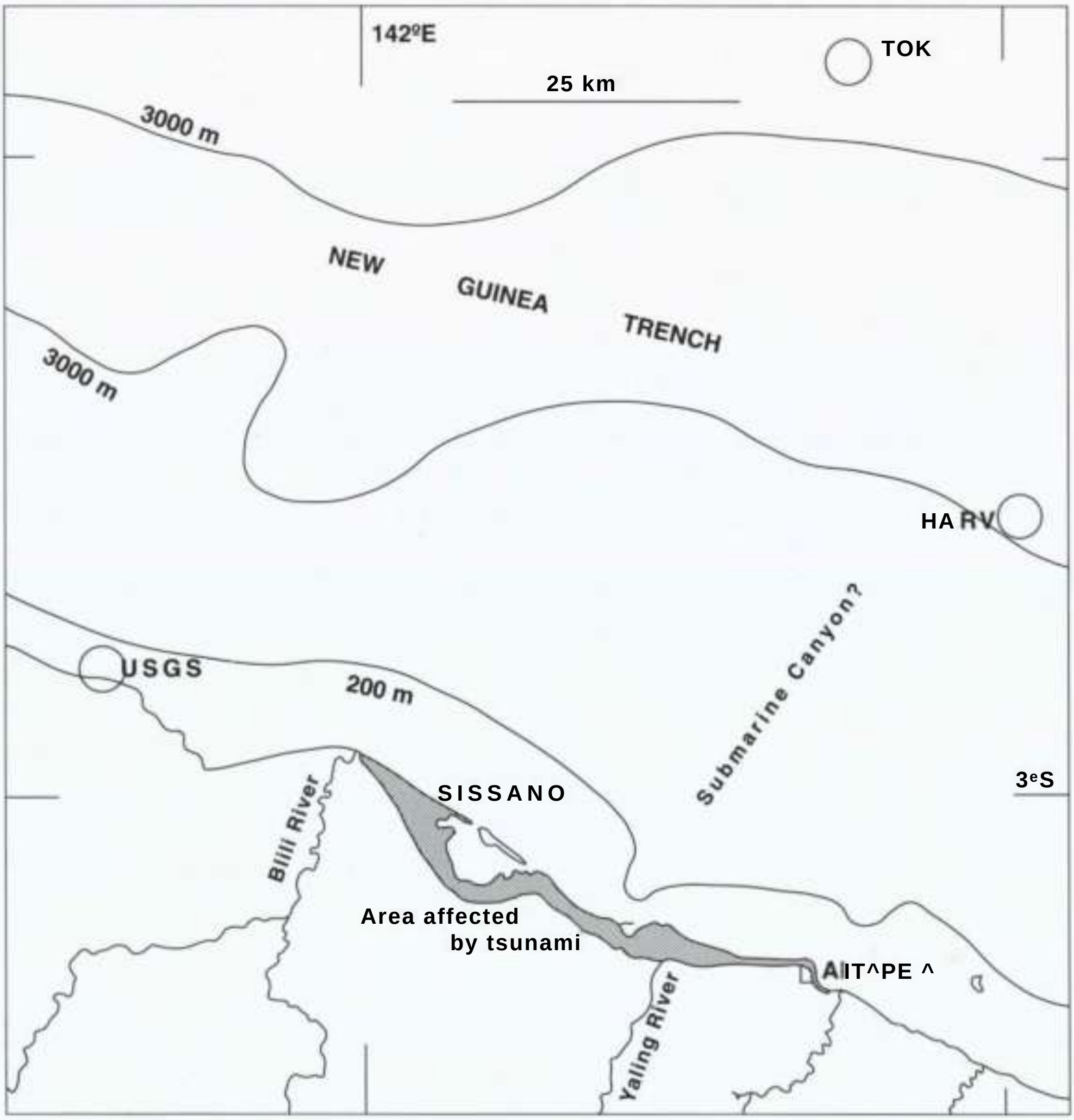
The 1996 Biak tsunami

Two and a half years ago, on 17 February 1996, a tsunami with a maximum height of 7.7m struck the north coast of Biak Island in Irian Jaya, causing extensive damage and the loss of 107 lives.

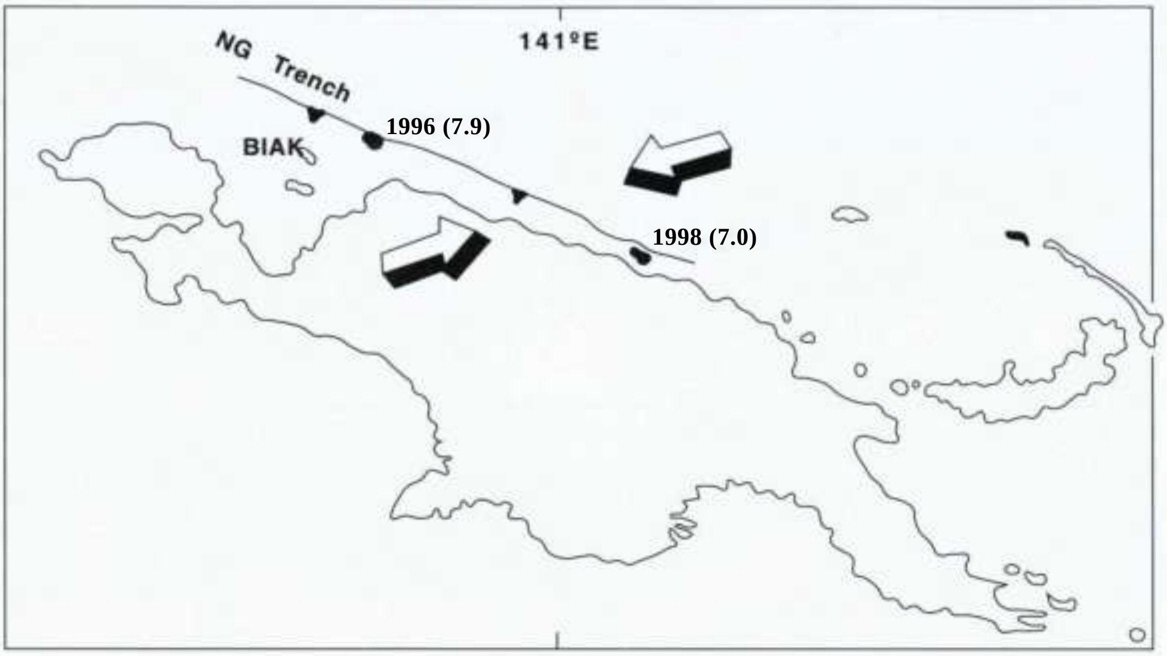
Biak is 700 km away from Sissano and at first glance the two events might seem quite unrelated. However, there is a connection, for both were caused by major earthquakes on the inner wall of the same structural feature, the New Guinea Trench (see map).

The trench is part of the boundary between the Pacific and Australian Plates, which converge here at the remarkably high rate of 11 centimetres per year (see arrows).

Incidentally, follow-up studies of the Biak tsunami by a team led by Fumihiko Imamura of Tohoku University showed that submarine slumping of sediments may have been a factor.

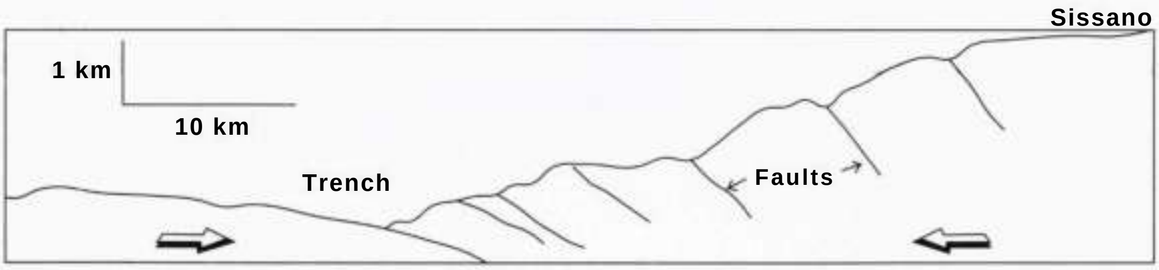


The map shows the location of the New Guinea Trench and of the epicentres for the earthquake of 17 July as determined by three overseas observatories: The United States Geological Survey in Denver (USGS), the Earthquake Research Institute in Tokyo (TOK), and Harvard University (HARV). Based on the kink in the 200 m isobath I have interpreted that there may be a submarine canyon off the mouth of the Yalingi River.



ABOVE: The New Guinea Trench marks the boundary between two plates. The Pacific Plate slides obliquely under the Australian Plate at a rate of 11 cm per year. The grinding together of the two plates gives rise to shallow earthquakes along the trench axis and as far south as the Bewani and Torricelli Ranges. A magnitude 7.9 earthquake on the inner wall of the trench in September 1996 caused a tsunami that took 107 lives on Biak Island.

BELOW: The cross-section across the New Guinea Trench is based on a seismic reflection profile. It shows the relatively steep slope of the inner wall of the trench, offshore fron Sissano, and a number of faults. Probably it was movement on one of these faults that caused the 17 July earth-quake and tsunami. The earthquake may have caused sediments to slump down the slope. The added effect of the sudden displacement of the ocean water by the sediments could explain the unusual power of the tsunami.



Safety lesson from tsunami

Earth Talk 4 August 1998

The decade since the civil war began on Bougainville in 1989 has been punctuated by a remarkable string of disasters.

Earthquakes and major landslides killed villagers in the Finisterre Range and closed the Highlands Highway in 1993, others were killed by flood and landslides in the Southern Highlands in 1994, and most of Rabaul town was destroyed by volcanic eruption later in the same year.

Another volcano caused the deaths of village people in a pyroclastic flow on Manam Island in 1996. There was loss and damage from Cyclone Justin and the severe drought of 1997, and then the great tsunami of 1998.

Now that the civil war has ended, perhaps the tide has turned and we can hope for a respite, a calmer decade, a time for flowers to grow and heavy hearts to mend.

In the meantime, villagers and aid workers are picking up the pieces and putting their lives together after the Sissano-Aitape tsunami. The human disaster was enormous: More than 2100 killed, many seriously injured, and 9,000 displaced to temporary accommodation in care centres and elsewhere.

The physical aspects of the disaster, too, are quite amazing: A succession of three waves the second of which may have reached a height of 15 metres, the inundation of a strip as wide as two to three kilometres of coastal lowlands, and the complete destruction of villages that were home to 12 000 people.

Now, 17 days after the event, we are still piecing together what exactly happened and why.

Geoscience teams from Japan and Australia are in the field this week, setting up a network of seismic stations and examining the evidence of wave heights and wave paths. I hope to bring you their findings next week.

From the outset the Japanese tsunami experts have been puzzled by fact that an earthquake of magnitude 7 produced such a massive tsunami, because their modelling, done after the event, indicated that the tsunami should have reached a height of two metres at most.

They have suggested that there must have been an unusually large displacement of the seabed by movement on a fault at the time of the earthquake. Alternatively, the earthquake might have triggered a massive submarine landslide which in turn would generate a tsunami.

Another possibility is that in some way the energy of the tsunami was focussed into the Sissano area by the seafloor topography. The few depth soundings that are available at the moment suggest the presence of a submarine canyon offshore from the the lagoon (see map).

Could this have had a bearing on the shape and size of the tsunami?

If indeed there were a major submarine landslide then it is possible that the shoreline has been destabilised and that there may be a risk of subsidence of parts of the coast between the Bliri and Yalingi Rivers.

Recall that the Sissano Lagoon was formed by coastal subsidence after a major earthquake in 1907.

Accurate and detailed mapping of the offshore shelf and slope would clarify whether there had been major fault displacement or a major slump, and thus tell us more about future risk.

As good fortune would have it, the German research ship Sonne is in Rabaul. Authorities are checking whether she can be diverted to the disaster area.

Another question that has arisen in the wake of the disaster is whether a warning could have been given. The simple fact is that, because the source of the tsunami (earthquake and possibly landslide) was close to Sissano-Aitape, there was not sufficient time for a warning to be given.

This is quite apart from the vexed question of how one would deliver the warning.

However, there is a public safety lesson to be learned from the disaster. We had become complacent about tsunamis and the risk they represent.

The message that needs be given to all coastal people, and especially those who live near the water's edge is this: If you feel a strong earthquake be aware that a tsunami may follow soon after. If you are close to the seashore, move quickly to higher ground.

Another question that doubtless will be raised after the dust has settled is our capacity to respond rapidly to a major emergency.

Preliminary reports suggest that more could have been done on the Saturday and Sunday to rescue the injured and to reduce the trauma of the other victims, had we put in more resources more quickly.

1999 Update:
The research ship Sonne was on a tight schedule and could not be diverted to the disaster area to map the sea floor. However, the Japanese research ship KAIREI was able to tackle the job some months later. The results are discussed on pages 47-48.

Fitting the pieces together

Earth Talk for 11 August 1998

The teams of visiting tsunami experts from Japan and the United States and seismologists from Australia returned to Port Moresby over the week-end and made their preliminary verbal report. From this we can now piece together much of the story of the Sissano-Aitape tsunami.

Firstly, and at the risk of sounding like a cracked record, we know there were two earthquakes on the evening of Friday 17 July, one at 6.49 pm and the other at 7.09 pm. The first event had a magnitude of 7.0 and the second may have been as strong or slightly stronger. The epicentre of the first event was somewhere within 50 km of Sissano and Aitape, probably offshore but possibly just onshore.

The first tsunami wave arrived at Sissano 15-20 minutes after the first earthquake. An initial lowering of sea level was followed by the arrival of a sea wave that swept across the sandbar and into Sissano Lagoon. Two other waves followed.

Most eyewitnesses describe the first wave as the most destructive, but there are others who observed that the second wave was larger and did more damage than the first.

The average maximum height of the tsunami waves as they crossed the Sissano sandbar was about ten metres. The wave heights were determined by the visiting teams, using indications such as the maximum height of damage to the fronds of coconut palms.

However, the wave height varied at different points along the sand bar and was as high as 15 metres above sea level along an unpopulated section of the sand spit.

The effects of the wave were seen as far west as Wutung, on the border with Indonesia, and probably extended into Irian Jaya. Around Wutung three waves came in like a tidal surge, reaching as high as three metres at the road bridge.

The wave is said to have arrived at Wutung at the same time as the second earthquake. This is about the delay that one would expect for a wave originating near Sissano. In the opposite direction, a sea wave less than a metre high reached Wewak.

The cause of the tsunami

Several lines of evidence point to an origin of the tsunami near Sissano. The best evidence is the extreme wave heights recorded on the lagoon sand bar. Another piece of evidence is that damage to structures at the mouth of the Bliri River, west of Sissano, was clearly inflicted by a sea wave that was travelling westward.

The maximum energy of the tsunami seems to have been narrowly focussed on to a 40 km strip of coastline between the Bliri River and Aitape and the energy to have fallen away rapidly to either side of this strip. The narrow focus of the tsunami is surprising.

However, the biggest puzzle is that an earthquake of magnitude 7.0 could cause such a massive and catastrophic tsunami. According to the standard models of the experts, such an earthquake should produce a tsunami no higher than two metres. Why was the wave five times greater than expected?

We mentioned previously two possible contributing factors: that there may have been a massive submarine landslide triggered by the earthquake; and that the energy of the tsunami may have been focussed by the contours of the sea floor slope off Sissano.

A third and intriguing possibility that came to light in our discussions over the weekend was that the tsunami may have been triggered by a gas explosion. Let me explain this.

Beneath the Aitape coastline and extending beneath the offshore slope seaward to the New Guinea Trench are packets of sedimentary rock separated by faults.Gas can be generated within the packets of sediment by the decay of organic matter, in the same way that the great gas reserves of the Kutubu and Hides fields, for example, were generated.

If the surrounding rocks are impermeable, the pool of gas in the sedimentary rocks may be held at considerable pressure. If the high-pressured gas is intersected by an oil company drill stem the gas may escape explosively, leading to a blow-out - the oil drillers worst nightmare.

In the same way, if fractures were to open above a highly pressured gas pool, triggered by the shaking of the earthquake, the gas will escape explosively, carrying with it a great volume of mud and rock up to the sea floor.

A gas explosion would explain the loud bang that was heard by some observers about five minutes after the earthquake.

What remains to be done

Although we now have a clearer picture of the events, some critical uncertainties remain. Some will be addressed by investigations that are currently under way.

Six newly installed seismic stations will accurately locate the sources of any aftershocks, and thus give clues to the exact location of the initial earthquakes. Similarly, responses to questionnaires sent out by the Port Moresby Geophysical Observatory will be plotted as a map of earthquake felt intensities and these will point towards the epicentres of the earthquakes.

Equally or more important is the gathering of more eyewitness accounts from people who were at different locations along the coast. In particular, the tsunami modellers are asking for information on the timing of the three sea waves and I, for one, am curious about reports that water in the tsunami waves may have been unusually warm.

The Sissano-Aitape area will be re-mapped using aerial photographs that are currently being acquired under AusAID funding. The new photographs may show evidence of land movements, and could show the limit of the run-up of the tsunami waves into the hinterland behind Sissano.

Similarly, mapping of the sea bed offshore from Sissano may reveal the trace of any fault scarp, and would certainly reveal any gas explosion crater or the scar of a major submarine landslide. If other ships are not available beforehand the RV Sonne may return in 1999 to carry out this survey.

The Arop villages extended along the sandspit that bounds Sissano Lagoon. People at Arop No. 1 village (picture) were carried across the lagoon into mangroves. The wave physically removed all trace of the villages except for some concrete slabs, a few house posts, and a septic tank (foreground). “The wave came like a thief in the night. When we returned to our homes we found nothing. Nothing was left” (Retired army officer Colonel John Sanawe).

The need to be fully informed

Earth Talk for 11 August 1998

Knowledge is the enemy of fear. This was brought home to me at the time of the seismic crisis and threatened eruption of Rabaul volcano in 1983-84 when my role was to liaise between the volcanologists and the public.

In such circumstances it is tempting to tell the people what you think they want to hear, so as not to alarm them. I quickly learned that that is the wrong road, and can only lead to mistrust and ineffectiveness.

At a time of fear and crisis, people want and need the facts, theywant and need and deserve to be fully informed. It was a learning experience for me to see that people can handle calmly even the most difficult and dangerous situations if they are fully informed.

With this in mind I approached Ludwick Kembu, the Director-General of NDES, early last week with a plan to take information about the tsunami to the people in the care centres.

Bolstered by his support I found myself on a rushed trip to Vanimo, Aitape and Wewak, armed with a bundle of 2,000 pamphlets that had been quickly put together with the help of my students and the good services of Cyril Nogah and staff of the University Printery.

It was all a very rewarding experience but it's too soon after the event to pick out the highlights and recount these for you. In essence, there clearly was a demand for the information and I can only hope that it brought some better awareness and ease of mind to those for whom it was intended.

In return, I learned much about individual experiences during and after the tsunami, and was able to refine the picture of the sequence of events.

The stories of survival that I heard were quite amazing and deserve to be recorded and stored for posterity. Perhaps I can reproduce some next week.

Several features of the tsunami became clearer to me from these conversations.

The three waves that comprised the tsunami moved very fast, perhaps 10-15 metres per second, and followed each other in quick succession, perhaps several minutes apart. There was no time for one wave to recede before the next arrived so they built up on each other.

In some locations, the first wave was preceded by a blast of air that had been caught and compressed in front of the wave and that was strong enough to knock people over.

At one part of Arop, the first wave crashed on the beach then swept hrough the houses "like a grass cutter", carrying people into the lagoon but leaving houses standing.

The next wave rode in on the back of the first and so did not break until it reached the houses, which it demolished.

The third wave followed soon after riding on the large volume of water brought in by the first waves.

The reports of the sea bubbling and of foul smelling gas, and also the reports of warm water, and water that stung the eyes possibly can all be explained as an effect of the disturbance of the stagnant bottom waters of Sissano Lagoon. This is speculation and remains to be checked but seems likely.

In normal times, the lagoon was calm and over the years a layer of vegetable matter would have accumulated on the bottom, thereby building up an oxygen-poor environment where hydrogen sulphide and other gases could develop.

When the waves swept across the lagoon the waters were overturned and the foul bottom waters brought to the surface.

Many people spoke of sudden darkness after the waves arrived and that the stars were blotted out. We can imagine that a great cloud of fine sea spray was in the air and formed a fog or low cloud through the evening, until about five in the morning by some accounts.

Another interesting aspect that has puzzled the experts was that the tsunami was barely recorded on tide gauges to the north of PNG. For example there was only a minor blip at Majuro. However, there was a small effect of the order of perhaps half a metre on western Manus, according to local reports - enough to wash canoes off the beaches.

If you have access to the worldwide web you can follow the story of the scientific investigation as it unfolds at http://www.pmel.noaa.gov/tsunami/ under the heading PNG Web-Link Compilation by Type of Data.

Resettlement

Meanwhile, the authorities and the people of the Sissano area are coming to grips with some difficult decisions about resettlement. Lands officers are in the area and talks and planning are progressing.

Currently, three of the six care centres are not accessible by road and so are reliant on helicopter drops for supplies, a situation that can't be sustained in the long run.

One of the options will be to re-locate near the coast, for this is the customary lifestyle.

With this in mind, I reproduce below the recommendations that were presented by the visiting team of tsunami experts a week or so ago.

These apply specifically to the Sissano Lagoon area.

1) People should not reoccupy village sites that are fronted by the ocean and backed by rivers or lagoons. Memorials should be built at the worst stricken places to remind future inhabitants of this disaster and thus discourage future habitation of high risk localities. These memorials could be simple such as large painted signs.

2) Schools, churches and other community facilities should be located at least 400 metres from the coastline, and preferably 800 metres in high risk areas.

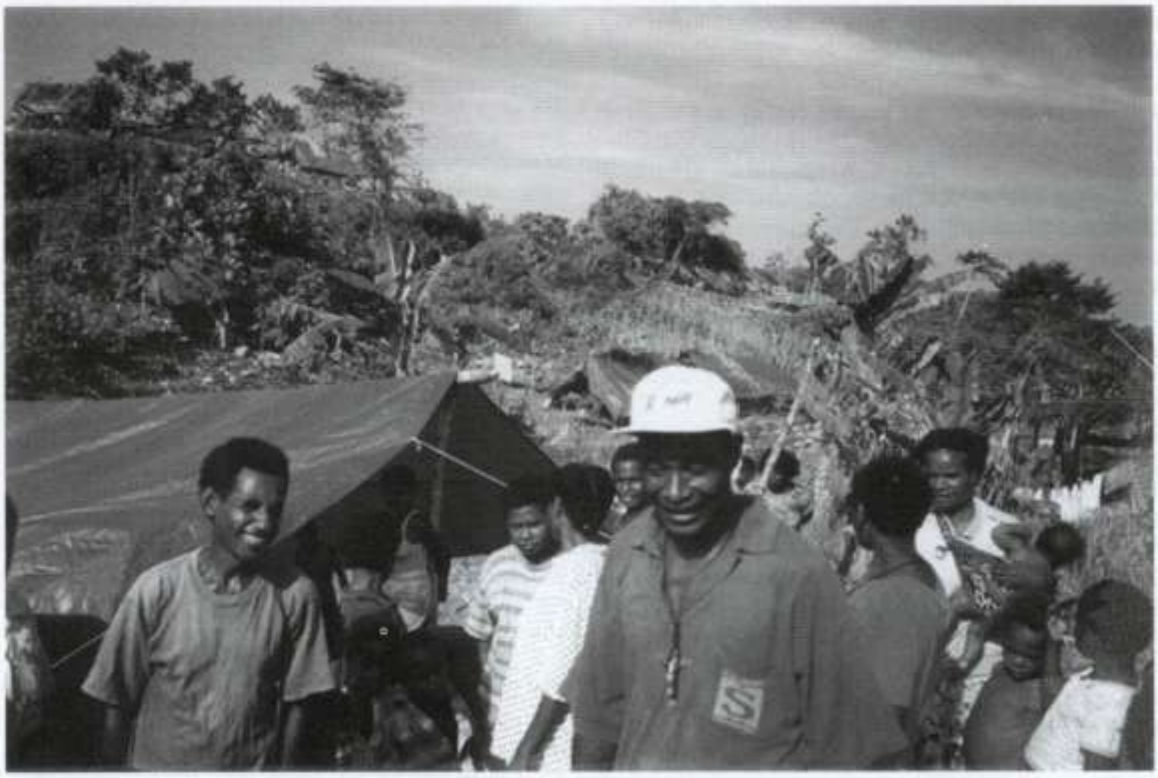
3) There should be evacuation drills annually on the anniversary of this disaster so that all people in high risk areas know that if they feel the ground moving they should run as far from the beach as possible.

4) Every family in a high risk area should have a designated casuarina tree with a ladder or carved steps to allow vertical evacuation of the able, when there is no other option.

5) The residents in non-affected areas should return to their homes, after being briefed about what to do in the event that they feel a ground motion or if they see unusual water movements. The first sign of the onset of most tsunamis is a drop in sea level.

6) The local casuarina tree species withstands the wave attack significantly better than palm trees, and casuarina forests should be planted in front of coastal communities, whenever possible.

7) People should be encouraged to resume fishing in the open ocean. The quality of the water in the lagoon should be monitored on a regular basis until it can be shown to be safe for fishing and habitation.



Olbrum care centre is on grassy limestone hills immediately inland from Sissano Mission and the Sissano villages. The vinyl tent flies that provided emergency cover in August 1998 (picture) were replaced by more permanent buildings in subsequent months. Olbrum will become a major new centre for the Sissano people.

The picture changes

Earth Talk for 25 August 1998

Late last week I made a hurried trip to Aitape and Sissano to continue a public awareness campaign, presenting information about the tsunami to local residents and discussing future risk.

During the discussions new information emerged about the events of the night of 17 July. The information came from students at the Aitape high school, patients in the Raihu Hospital, counsellors, and from a Sissano man who, amazingly enough, saw the the whole show from the verandah of his undamaged house.

The information is preliminary and the picture may change as more people come forward with their stories. In the meantime it's the best we have. The story has become more complex!

One fact that surprised me is that, although the first earthquake was felt strongly and lasted for several minutes in villages in the Sissano Lagoon area, it was felt only weakly by people living 25 km to the east at Aitape.

For Aitape residents the second earthquake was the vigorous one and lasted possibly as long as five minutes. One of our students who was at Raihu Hospital that night noted that the shock waves of the first earthquake arrived from the north, rattling the rooves of St Ignatius High School before reaching the hospital, but the shock waves of the second earthquake arrived from the southeast. This kind of information is especially useful because we do not have a good fix on the location of either earthquake.

Returning to the main story, the tsunami reached the Sissano Lagoon sandbar within 17-19 minutes of the first earthquake and reached the Aitape coast 3-5 minutes later, arriving a few minutes after the tremors of the second earthquake had ceased.

Back at Sissano village and mission, our eyewitness observed that the wave struck obliquely from the northeast, rather than straight on to the shoreline as was the case at Arop. Similarly, the international team had concluded that the wave struck the mouth of the Bliri River obliquely from the east-northeast.

The obliquity of the waves at Sissano and the Bliri mouth, the delay in the arrival of the wave at Aitape, and the focussed fury of the wave in the devastated area between Warupu and Arop all suggest that the tsunami originated directly offshore from the Sissano Lagoon and perhaps as near as 10 or 20 km from the coast.

Another interesting observation from our man at Sissano was that, at least at his observation point, the third wave was bigger than the first or second. Other survivors had thought the second wave bigger.

Public awareness

The public awareness campaign has now been taken to people in all of the care centres, to survivors in Vanimo, Wewak and Raihu hospitals, and to students at Aitape High School. The presentations begin with an explanation of what tsunamis are and the information that, around the Pacific, tsunamis are a fairly common phenomenon. I then move on to discuss the likely cause or causes of this tsunami in particular, and then address the 64-dollar question of what may happen in the future.

In order to predict the future we can look at the past. The record shows that in the past 110 years, although there have been many small tsunamis, there have been only four major tsunamis in PNG waters, one off New Britain in 1888, another off Buna in 1895, another off the Bogia coast in 1930, and now the Sissano-Aitape tsunami.

The visit to Aitape High School was a special night for me, a group of 450 bright young people assembled in the school mess hall. The students gave me more information about their experiences of the earthquakes and asked a series of questions. Time flew by.

At the end, and after most of the students had dispersed, two small groups remained, one comprising senior girls and the other, senior boys. Both had the same question. Had I seen the pamphlet that is said to show a satellite view of the tsunami and that includes images of the devil and other biblical figures, and if so what did I think about it?

I had in fact seen this pamphlet the previous week. It shows a stylised tsunami wave from side on, like a big mushroom or stook of hay, and decorated by the various biblical figures.

Clearly this was not a picture taken from a satellite (which would have shown the wave and coastline from above, forgetting for the moment that it was already dark when the wave formed). Rather it was the product of someone's skill with computer graphics, cutting and pasting, and a photocopier.

I mention this only because it illustrates how the distribution of false information or propaganda can have such a negative effect at a time of crisis when all hands should be promoting truth and factual information.

Incidentally, the duty teacher who chaired the meeting told me later that many of the students who had experienced the tsunami are still not able to talk about their experiences, despite the good efforts of counsellors. Let's hope that time will heal.

Last week I promised you some survivor stories but it seems I'm out of space so I'll just include one, my favorite, recounted secondhand.

This is the story of a teacher, a large man, who was carried into the lagoon by the first wave and found himself struggling and short of air deep inside the frothing waters. A dolphin came between his legs and lifted him to the surface. At the moment that he reached the surface the backwash from the first wave returned across the lagoon and met the incoming second wave. This made a vertical surge that lifted him bodily and threw him into a nearby dinghy. He and the dinghy then rocketed across the lagoon but parted company as they capset into the mangroves. Em nau!

Below

Students assembled for a tsunami information presentation at Aitape High School. Most students live in at the school. On the day of the tsunami some had gone home to their villages because of the holiday break.

Tsunami warnings

For most tsunamis in PNG and region it is not possible for the authorities to give a warning. This is because the tsunami will arrive within 10-30 minutes of the earthquake. So it becomes the task of each person to recognise the tsunami warning signs and take action accordingly.

Don't wait to be told.

Learning from the past

Earth Talk for 1 September 1998

On the evening of Friday 17 July, the people of the Malol-Sissano coast experienced a most strange and terrifying event: the surging of the ocean to unimagineable heights and the crashing of great waves on and through their peaceful villages.

For those of us who were not there it is very difficult to imagine the events or the fear and emotions that ensued as people struggled for their lives and for the lives of their children and babies.

Two television shows during the week went some way towards recapturing the moment. The first, by Mark Davis, was shown on the ABC Four Comers program.

Davis took his camera to the Ramo care centre soon after the disaster and stayed on for perhaps a week, interviewing and filming the survivors. It is a remarkable and intimate record of how it was, and goes beyond the immediate tragedy to provide a touching insight into the history and present plight of the Warapu people. Let's hope the show can be repeated on national EM TV so more can see it.

The second screened on EM TV and was the work of the inimitable Father Zdzislaw Mlak, who has done much to record contemporary PNG on tape, and the equally inimitable John Eggins.

It opened with amateur video footage that showed the peaceful villages as they were before the disaster, a pictorial record that is now beyond price! This was followed by footage of the same sites as they are now, stripped of all buildings and most vegetation, and with sheets of iron wrapped around trees like so much waste paper. The tape went on to recreate that awful night and its aftermath through interviews and pictures.

I've watched the show twice, fascinated, and would watch it again and again. One can only marvel at the force and fury of the waves that could cause such damage, and at the fortitude of the survivors who suffered injuries and loss so stoically, and of those who worked tirelessly through the first few dreadful days to help them.

Meanwhile, small pieces of the story of that night continue to emerge, like pieces of a jigsaw puzzle that need to be fitted into place. During the week there was the report from Colonel John Sanawe of an explosion on the skyline before the wave developed, and I heard a secondhand report that fishermen had noticed bubbles and a sulphurous smell rising from a reef 24 hours before the tsunami.

The 1935 tsunami

Another story that has surfaced recently, and was retold in the Mark Davis tape, is that lives may have been lost in the Arop-Sissano area during a tsunami in 1935. However, some doubt remains. For example there is nothing in the official records from that time.

J.K. McCarthy, the kiap at Aitape at that time, was aware of deaths by landslide in the hills but not of deaths by tsunami. McCarthy left us with a vivid record of the scene at Aitape in his book Patrol Into Yesterday.

"I was swimming off the beach at Aitape when 1 heard a noise like thunder. But there were no clouds in the sky and I decided it was my imagination. Yet was it? Waist deep in the surf I found myself staggerring to keep my balance. I walked towards the beach and was astonished to see the casuarina trees swaying, and a moment later was thrown to my knees with a violent jolt. I saw some branches of the trees break off and heard native shouts of 'Guria! Guria!' and knew finally that it was an earthquake."

The date was 20 September 1935. This was the magnitude 7.9 earthquake centred somewhere in the Serra - Sissano area, west of Aitape, that was discussed in an earlier Earth Talk. McCarthy had lived in Rabaul and knew what gurias were about. However, this was something new. "The earth did not shake; it jerked in a series of convulsive movements that seemed to be up and down as well as sideways.

'"The sea! Look at the sea!' I heard some natives shout, and 1 saw that the ocean seemed to be receding from the beach. After the first violent series of shocks the tremors diminished until they were barely discernible, but the sea was now pulled back until the whole of the foreshore was dry; then, as I watched, the tide started to return. It came in great breakers although the outer sea remained calm. The great waves swept up over the coast towards me and in places flooded inland. Where the land was low the sea went many hundreds of yards inshore. By evening the sea was calm again and so was the land, and we had time to look at the damage and count the dead."

On the Mark Davis tape there also is mention of a tsunami at Arop in 1953. I searched for a record of this in Ian Everingham's Preliminary Catalogue of Tsunamis for the PNG/Solomons Region but found none. However, there is an unofficial, perhaps questionable, record of a damaging tsunami early in 1951. An unnamed observer wrote:

"There had been intermittent earth tremors all day. The wave came in suddenly in the afternoon and swept away three wards of the old hospital, which was built of native materials. The waves were approximately 20 feet high. No casualties."

The magnitude 7.0 earthquake of December 1907 that caused the subsidence the Sissano Lagoon may have produced a tsunami, but the evidence is doubtful. Everingham suggests there was a 2-4 m wave, based on a geological report written in 1935, but contemporary records make no mention of a tsunami. The record of past tsunamis is especially relevant now that plans are being made for re-settlement of those displaced by the 1998 tsunami. The lesson is that living on the coast at Aitape and westwards is fine, but houses and schools must be placed where there is minimum risk from tsunamis, either on high ground or at distances of 400-800 m from the water's edge.

Below:

1. The original church at Sissano (then Aisano), built by German Divine Word missionaries in 1911. This was replaced in 1926. Photograph reproduced by kind permission of Schubert Rainbubu.
2. The priest's house at Malol (originally the Sisters' house), built by SVD missionaries in 1926 using pre-cut pieces shipped from Germany. This is now the only building dating from that era, the contemporary church at Sissano having been destroyed by the 1998 tsunami.

Was there a mud volcano?

Earth Talk for 8 September 1998

Two tsunamis with wave heights of up to 10 metres struck the northeast coast of the North Island of New Zealand on March 25 and May 17, 1947. Fortunately this part of the coast is sparsely settled and little damage was done.

Both of the tsunamis were associated with offshore earthquakes of magnitude 6 or less.

According to the experts there is no way that earthquakes of that magnitude could generate a 10-metre wave.

Thus there are similarities with the Sissano-Aitape tsunami, which was much too big to have been generated by the accompanying magnitude 7 earthquake.

Another similarity is that the geologic setting of the NZ northeast coast is remarkably similar to that of the Aitape coast, with an active plate boundary marked by a deep sea trench some tens of kilometres offshore, and young wet sediments stacked by faulting beneath the inner wall of the trench.

So what can we learn from the NZ events that may help us here in PNG?

The NZ scientists concluded that the tsunamis were generated by mud diapirism on the seafloor. What this means is that a large volume of mud and rock fragments emerged rapidly on to the seafloor, driven from below by escaping gas and oil.

The great pile of mud and rock fragments displaced sufficient sea water to generate the large tsunamis.

The same process has been called a mud volcano but this is not a very good name because it suggests volcanic activity, which is not the case. The driving force is gas that has been generated in the buried sediments, rather than volcanic gases.

Travellers in Enga can see an example of a mud diapir of a much smaller and more gentle kind near Lake Inim, between Wabag and Laiagam.

Could the Sissano-Aitape tsunami have been generated in the same way? There are several lines of evidence that suggest this may be so.

Firstly, a number of survivors have spoken of a smell of kerosene or diesel in the water of the wave. This information is drawn from the responses to questionnaires that were circulated by the UPNG counselling team.

A similar story is told by Colonel John Sanawe who returned to Arop No. 1 on the morning after the tsunami and noticed a coating of a light oil similar to diesel on the grass and on leaves.

Other stories that suggest mud diapirism were given to me by fishermen from Nimas who are now at Rowoi care centre.

John Kimene was one of a group that was fishing on a shallow bank about 10 kilometres offshore from Arop on Thursday morning, July 16. This is a popular and well-known fishing spot with a water depth of 40-50 metres.

As the party trolled one or two kilometres west from the bank they were surprised to run into a succession of 2 to 3-metre waves that loomed and steepened as though about to break.

This they took to be evidence of a new shallowing of the water in an area that previously had been quite deep.

Next day at about noon Tom Kaisiera, a teenager from Nimas, paddled to the same general area and was surprised to suddenly find the sea bubbling. The bubbling was apparently caused by the escape of an odourless gas. The area of bubbling was large, perhaps 100-200 metres across and there was a smell of dead fish in the air.

This was nearly the end for Tom, who found his canoe being drawn into the bubble zone by a strong current. He escaped only by paddling for dear life.

So what can we make from these scraps of information?

Firstly, the fishermen's story suggests that there were some changes in the shape of the seafloor off Arop on the day before the tsunami, perhaps the result of a mud diapir and perhaps driven by the upward movement of gas.

Secondly, gas had started to escape from the seafloor by noon on Friday.

If a gas-driven mud diapir existed then the earthquake of Friday evening was perhaps the stick that stirred the possum.

The shaking could have freed more gas and caused the diapir to accelerate in speed. The resulting rapid emergence of a large volume of gas-lubricated mud and rock fragments on to the seafloor would then have triggered the tsunami.

This idea can be tested. A survey of the seafloor offshore from Malol-Arop-Sissano is planned for some time in the next 12 months, and seismic reflection surveying, which involves the bouncing of sound waves off the layers of rock beneath the seafloor, would quickly show whether or not mud diapirs are present.

Although they were unhurt by the tsunami, the people of Rainuk and the adjacent villages were concerned by what they had seen and by the continued shaking of the aftershocks, and so headed inland for safety.

Most remained inland in temporary quarters for the following five weeks. In fact some are still there. Others have returned in sufficient numbers so that the primary school could be re-opened last week.

The stories from other areas that were only marginally affected by the tsunami are similar, for example at Leitre to the west of Serra and Lemieng east of Aitape.

There is still a long way to go and much work to be done before life on this otherwise idyllic coastline returns to normal and people regain their peace of mind and customary sea-going way of life.

Fear of the sea:

It is now seven weeks since the tsunami struck and life is returning to normal for many. However, fear of the sea remains.

One of the objectives of the social workers and counsellors who are working in the area, and of the public information program that I have been working on, is to allay that fear.

Over the past weekend I visited Rainuk village in the Serra area, about 15 km west of Sissano. At Rainuk the tsunami had surged up over the beachfront sand ridge but had caused no damage and no loss of life.

Generally the sea floor offshore from the Serra coast appears to drop fairly steeply and this is probably the reason that there was no breaking wave.

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All that remains of the Sissano Sub-District Office are the steel footings and parts of a cement-brick water tank and the septic system. The office was located 300 m from the water's edge, between Warapu and Nimas villages. According to eye-witness reports the building was knocked over by a blast of air immediately before being hit by the wave.

What history can tell

Earth Talk for 15 September 1998

For the past several years our two major universities have struggled to maintain their academic programs in the face of reduced funding. This has caused a certain amount of soul-searching and debate about cost-saving measures.

Should we try to continue to teach the same programs with less money, or should we cut some programs entirely so that other programs can be properly funded.

One of the options that was suggested to me by someone in senior management, I hope with tongue in cheek, was that we could eliminate the History Department. I suppose the argument that can be made for deleting the history program is that yes PNG needs engineers and scientists but doesn't need a lot of historians.

So the question arises, do we need to teach history. How does it benefit us. I can think of several answers. One is that each of us needs to know where we come from, to understand the experiences and principles that have guided our ancestors, and thereby to better appreciate our culture.

For example, our students may or may not be aware that for many their bloodlines extend back through at least 40 000 years of habitation of these islands and that their traditional customs and values have evolved through that time.

This alone is surely a reason to be confident and proud and to not feel inferior in the company of lecturers and employers from the western world, with their superior technology and greater wealth.

Another reason I personally would hate to see our history program weakened is that our campus would be a much less interesting place if we were to lose our history professor Ron Huch.

The most cogent argument for the study of history is that if we do not learn from history then we are condemned to repeat the mistakes that have been made in the past.

This is true of history in the conventional sense and explains the continuing public fascination with the rise of Hitler, for example. How did he rise to power and commit the world to a dreadful war, and could it happen again.

It also is true of our struggle to guard against and prepare for natural disasters. Ah! At last he's getting to the point, you say.

For example, our predictions of how Rabaul volcano will behave in the future are based primarily on how the volcano has behaved in the past, as seen in the historical and geological records. The rock record shows us how the volcano has behaved over a period of half a million years, and the written record tells us of the last 150 uyears.

Historical tsunamis

Similarly with tsunamis we rely to some extent on the written record about which parts of our coastline have been affected in the past, as one means of predicting what may happen in the future.

Fortunately for people like me there is an excellent compendium that was produced by Ian Everingham in 1977. This work is the basis for my bottled history of dangerous tsunamis in PNG waters, as follows.

The earliest recorded major tsunami was in 1855 or 1856 and wiped out the former village of Arulu near the mouth of the Kabenau River, on the Rai coast south-southeast of Madang.

Our information is from the diaries of Nicolai Mikloucho-Maclay who lived on this part of the Rai coast in 1871-72, 1876-77 and 1883 (Mikloucho-Maclay: New Guinea Diaries 1871-1883, Kristen Press Madang 1975).

Maclay had returned to New Guinea in late June 1876 and landed at Gorendu, two kilometres east of modern Ileg. He was astonished to see that during his time away large sections of the upper slopes of the Finisterre range had been stripped of vegetation by landslides triggered by earthquakes.

"I also learned from the natives that long ago, before my arrival in 1871, the entire village of Aralu, lying close to the seashore between the Kabenau and Koli rivers, was completely washed away by a huge wave, together with its inhabitants. As this happened at night all the inhabitants perished; only a few men who happened to be guests in another village remained alive but did not wish to return to live at the old place. So they settled at Gumbu, which escaped the disaster, being built farther from the seashore." [Gumbu was about 1 km west of the Kabenau River mouth.]

"The destruction of this village [Arulu] was well remembered by people not particularly old, and I surmise it happened about 1855-1856. After this catastrophe there were outbreaks of disease with fatal results on the Maclay Coast. This latter happened, I surmise, from the decomposition of the organic matter washed up on shore by the waves and its rotting in the sun."

1888 was the year of the next major tsunami, one we have mentioned previously, caused by the almost complete collapse of Ritter Island volcano off the western tip of New Britain. The resulting megatsunami reached a height of up to 12 metres and devastated much of the New Britain coast.

Next was a catastrophic tsunami at Buna in the Northern Province in 1895. The wave was about six metres high and travelled as far as 4 km inland to Ononda where "even today, so I am told, lumps of coral can be found" (J.R. Horne quoted by Everingham). At least 26 people were killed.

The same tsunami may have been witnessed by a resident magistrate visiting the Amphlett Islands, north of the D'Entrecasteaux Islands, in March 1895 who wrote of a two-metre wave from the west that carried large blocks of coral and other debris up on to the beach.

Other fatal tsunamis were in 1906 at Gasmata, triggered by a magnitude 8.4 earthquake, and in the Ninigo Group of islands west of Manus and along the Madang-Bogia coast in 1930, triggered by a magnitude 6.5 earthquake.

We learn from Everingham's catalogue that most of our coast is vulnerable to damaging tsunamis. Coastal facilities such as ports, power plants, telephone exchanges and public buildings must be located with this in mind, so that they are not at risk, and coastal people need to be aware of the risk, to know how to recognise the signs, and to know what to do when they see those signs.

On the west coast of Tumileo Island fragments of coral up to a metre across were broken from the fringing reef and carried ashore by the wave. A carpet of smaller fragments extends for 20-30 m inland (picture).

"....most of our coast is vulnerable to damaging tsunamis. Coastal facilities such as ports, power plants, telephone exchanges and public buildings must be located with this in mind, so that they are not at risk, and coastal people need to be aware of the risk, to know how to recognise the signs, and to know what to do when they see those signs"

Engineers focus on disasters

Earth Talk for 22 September 1998

The engineers of Papua New Guinea will meet in Rabaul later this week to talk about Engineering in Natural Disasters - survival, relief and restoration, surely an apt choice of theme for PNG in the 1990s!

Paul Arnold, Ronnie Akis and the other organisers have strung together a program that includes discussion of the dangers posed by Rabaul volcano, the restoration of Rabaul town, the effects of the 1997-98 El Nino, floods and dredge operations on the Fly River and, of course, the Sissano tsunami.

Engineers are a bit different from the rest of us. My dad and brother were engineers, so I know.

Dad graduated from the Kalgoorlie School of Mines working as an underground miner and studying part time. He quit from the mines because of dust on the lung and moved to Perth in the '20s to become a water supply engineer. His lasting memorial is in the water supply scheme that serves the dry inland towns of the Western Australian wheat belt.

This was an expansion of the goldfields water scheme constructed in the 1890s by that visionary engineer, C.Y. O'Connor. Poor O'Connor was subjected to so much public ridicule at the time that he took his own life. Such damage small-minded people can do!

Brother Mervyn and I were at UWA together so I had to listen to the jibes (true to a point) that most geology students were people who wanted to be engineers who failed the engineering maths courses.

Later I worked with Comworks engineers on the investigation of the Upper Cotter dam site outside Canberra and the Sirinumu dam sites outside our dry and dusty city.

I learned a lot from them, and I hope they picked up something from me, though mostly they seemed to regard me as a slightly lower form of life, on hand to do the work that was too dirty or sweaty for them.

At Sirinumu we had an idyllic camp above the river. No raskol worries then. Just myself and the driller, Jan Allis, a lanky Latvian who had served with the German army, fit man tru-ia.

We were a good team, worked together through the day and sat and chatted in the evenings (well actually Jan talked while I tried to study for my Masters degree).

At the end of each week 1 would do a supply run to POM and fit in some socialising and football games, but Jan preferred to stay in camp.

Some months later, when I was no longer involved in the project, Jan had a terrible accident. He had bought an old Landrover so that he could get out of the camp on weekends. One Sunday morning he drove out of the camp after rain.

If you have driven on the Sogeri Plateau you know how slippery that red clay soil can become after rain. As Jan drove up the steep slope from the camp that morning, the tyres lost traction and the vehicle slid slowly backwards, slewed to one side, and then rolled.

Jan was thrown out and the vehicle fell across his legs, crushing the bone and leaving him helplessly trapped.

I don't know how long it was before help came - it must have been hours. No-one else lived nearby at that time. I visited Jan in the hospital some weeks later. Both legs were in plaster and there was a terrible stench in the air. Subsequently I learned that infection had set in under the plaster and one leg had to be amputated. Poor Jan, a man who lived for the outdoors.

Well, to return to the topic of engineers and engineering. One of the engineering truisms that I learned in those years is that absolutely any engineering task that you can dream up can be accomplished, even the most seemingly unattainable, provided that there is enough money.

I suppose a good example is JFK's undertaking back in the 1960s to put a man on the moon within a decade.

Thus, as an engineering project it would be possible to make Sissano Lagoon a relatively safe place in the event of a future tsunami. Perhaps the engineers would put some steel baffles or piles of rock offshore to dissipate the energy of any wave, and construct a series of escape routes or emergency shelters.

I'm not saying it should be done. Just that in engineering terms it is possible.

It becomes a question of risk assessment - what is an acceptable level of risk; and of economics - costs and benefits.

Beyond these considerations there is a policy decision as to whether the authorities want people to go back, and the decision of the people themselves as to whether and when they might want to go back.

The 1930 tsunami

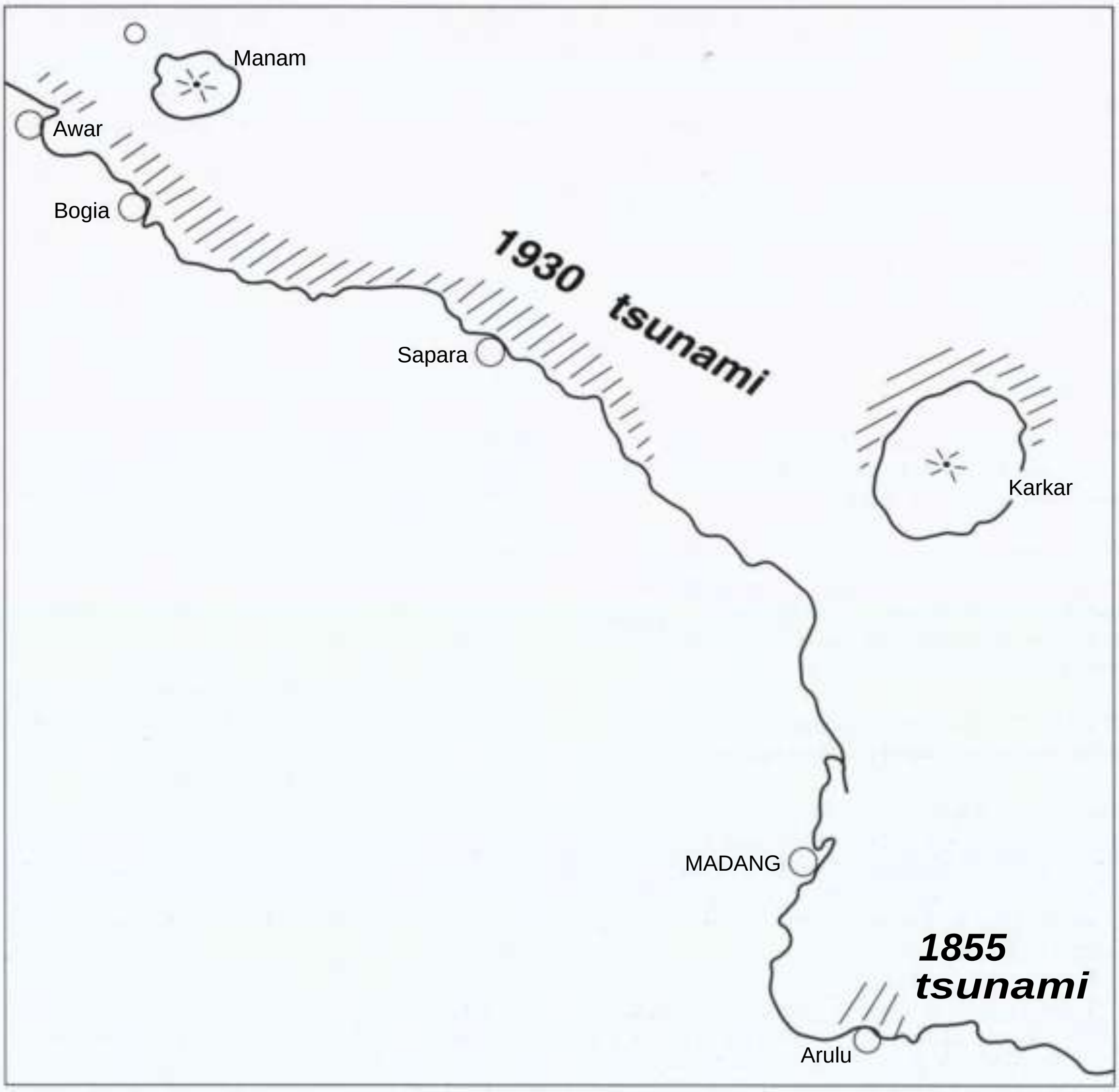
I have a little more information on the tsunami that struck the Bogia coast in 1930. The tsunami arrived at 7.30 on the morning of Dec 24 and swept an 80 km section of coastline southeast from Awar plantation.

Sapara, about 55 km southeast of Bogia, was hardest hit. Sapara was a mission station, and remarkable for a magnificent new church capable of seating 1,000 people.

On the morning of the tsunami Father van Baar was in the school preparing lessons when he was told that the sea had run up under his house. He went to the beach and saw that the sea had receded by about 400 m. Then the sea turned and a second wave, 6 to 7 metres high, approached at speed.

The watchers turned and ran for their lives into the bush or down the road towards Meriman, but were eventually caught in swirling waist-deep water.

They looked back to see the wave sweep away Father van Baar's house and the magnificent church. Five people were killed. Sapara Mission was not rebuilt and the mission was moved to a new and safer location.



In 1855 or 1856, Arulu village near the mouth of the Kabenau River, on the Rai Coast SE of Madang, was destroyed by a tsunami. The wave came at night and all inhabitants were killed.

In 1930, on the morning of Christmas Eve, Sapara Mission was destroyed by a 6-7 m wave. However, only five people were killed. It is said that at that time the people still remembered the Ritter Island tsunami of 1888 and so knew to run inland, and that this is why so few were killed. The 1930 tsunami also killed five people in the Ninigo Islands, 250 km west of Manus Island.

Tsunami history in the sand

Earth Talk for 20 October 1998

It's surely about time I brought you more news on the Sissano-Aitape tsunami, so here's a sandy story.

A week or so ago Honours student Michael Nongkas and I were in the field with two United States government geologists, Bruce Jaffe and Guy Gelfenbaum, looking closely at the sand that was left behind after the tsunami retreated.

This is sand that was caught up in the wave as the wave approached the shore and then was dropped from the wave after the water slowed or stopped moving.

The Americans, well actually Michael did most of the heavy work, found a thin layer of sand almost everywhere that the wave had been. The layer ranged from a few cm up to 12 cm thick. They sampled the sands carefully for further study here at UPNG and back at their home base in Menlo Park, California.

You might ask why?

The reason is that we need to know the characteristics of modem tsunami sands so that we can recognise them in the past record.

If we find a sandy layer in bedded sediments we need to be able to tell whether it originated from a tsunami or in some other more normal environment, such as wave action on a beach, wind action in sand dunes, or on the bed of a river..

If we can be sure it is a tsunami sand then it tells us something about tsunami risk in that area.

The surge of interest in tsunami sediments has been driven by the discovery of old tsunami sediments near the city of Seattle in the northwestern United States. The sediments are 300 years old and provide evidence that waves up to 20 m high swept the Seattle area 300 years ago.

Before this discovery people had assumed that coast of Washington State was safe from tsunamis. There was no mention of catastrophic tsunamis in the written historic record but of course that record goes back less than 200 years, when the first settlers of European origin reached the west coast.

The discovery caused a major re-think of the hazards faced by the cities on the west coast of the United States. In typical American fashion it also led to a concerted program of action, the National Tsunami Hazard Mitigation Program.

The program included preparing maps of the coast so that people would know what parts might be flooded by a tsunami, setting up signposts that showed the best escape routes if a tsunami should come your way, and a public awareness campaign in schools and the media.

Well back to our story. The American geologists also were interested to help us look for evidence of previous tsunamis. Such evidence will be buried beneath the modern sands and muds and the way to get at it is to dig a pit or, if you're in a hurry, use a gouge corer.

The gouge corer is a steel tube with a handle on the top. The tube has been cut in half lengthwise. The operator pushes the tube into the ground, rotates it, then withdraws it with the sample intact in the half-tube. Well, that's the theory. As you can guess it isn't always that easy.

So what did they find?

In almost all of the cores there was dark mud broken only by a thin layer of sand at about 120 cm below surface. Very likely this is a tsunami sand but until the sediments are dated (and that's not easily done) we won't know how old.

One possibility is that the sand is from a tsunami in 1907. We know that Sissano Lagoon and other smaller lagoons nearby formed by subsidence at the time of a major earthquake in 1907, and possibly there was a tsunami at that time. Alternatively the sand layer could be as much as 1000 years old

And what else is new?

The first reports from the international teams are trickling in. The Japanese scientists get top marks for prompt and open reporting of their results, with the other countries lagging far behind.

The delays in reporting can be because the scientists are under pressure to meet other commitments or are unwilling to put their results on the table for fear that others will publish their data. Yes, the science world is like that!

The delays are not helpful to us here in PNG and I am using an email cattle prod (I wish) to stir our overseas friends into action. Meanwhile some aspects of the tsunami have become clearer as the weeks roll by.

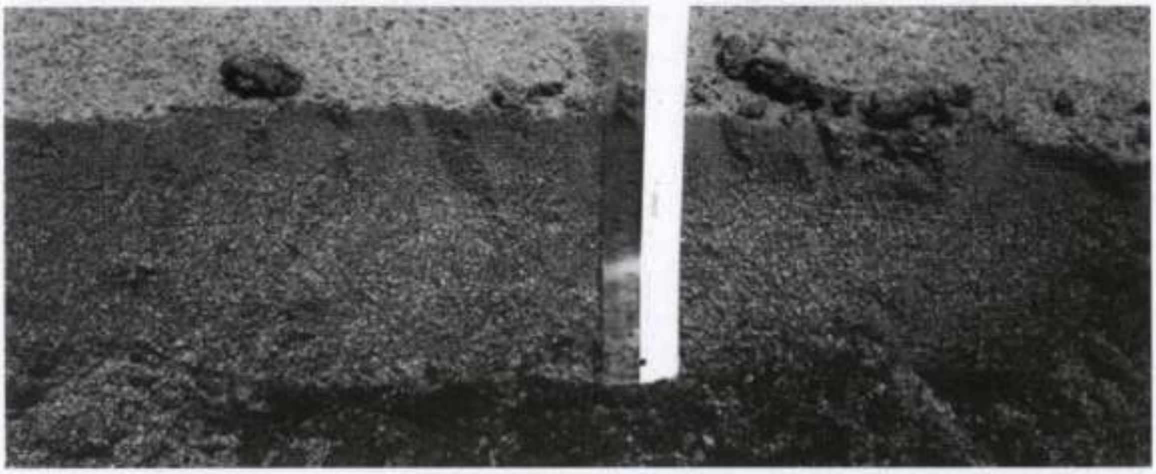
For example, we are now reasonably sure that the tsunami originated as a result of a shallow earthquake located about 20 km from the coast directly offshore from Sissano Lagoon.

The location is indicated by the path of the tsunami wave front which spread to west and east from this point, and by the preliminary results of aftershock studies, as given to me by the Australian team.

Horst Letz at the Port Moresby Geophysical Observatory is working up the aftershock results and will have more precise locations within the next month. Horst also is digging in the German histori-crecords for information about the 1907 event .At present we know very little about it.

I am in Aitape this week helping to quell rumours that are sweeping the care centres of bigger and worse disasters to come. Some of the rumours have been started by religious sects.

If there is free time on the same trip I will be looking to start identifying the factors that caused some coastal houses and villages to be destroyed while others nearby were preserved. This sort of information will be valuable for all coastal communities.



ABOVE: In the grounds of Warapu school, 7 cm of tsunami sand was deposited on top of the original dark clay-rich soil. Notice the change in grain-size of the tsunami sand, from coarse at the base to fine at the top. The evidence from this small excavation suggests that there have been no other major tsunamis in the interval of time since the dark organic-rich topsoil developed.

BELOW: At Tarau Point, east of Aitape, a wave two metres high came ashore and struck the rocky headland. Houses in a small settlement on the waterfront were destroyed and, within the settlement, a pothole about 10 m across and at least 1.7 m deep was scoured then filled with sand before the wave retreated. In the photograph Andrew Saken attempts to find the bottom of the sand deposit.

Getting reliable information to the survivors

Earth Talk for 27 October 1998

Over the next few weeks I want to bring you the latest information on the Sissano tsunami, including some new ideas on the earthquakes and the size of the wave. Today's topic is getting information to the survivors - the public information program.

The program involves presentations in care centres, schools, hospitals and villages. The object of the presentations is to help people understand what happened and thereby to give them some peace of mind. Costs of the program have been met by Orogen Minerals.

The presentations usually follow a pattern. First there is an explanation that tsunamis are a part of the way of life in all of the countries of the Pacific rim and that PNG has a history of tsunamis including at least four in the last 110 years that have taken lives.

The Sissano tsunami was caused by an earthquake. Any time in the future that there is a strong earthquake there could be another tsunami. This applies equally anywhere along the coastline of Papua New Guinea.

If there is another tsunami in the Sissano area it is unlikely to match the size and power of the 1998 event simply because most of the tsunamis recorded in PNG history are smaller, at between one and two metres high. The 1998 event was exceptional.

However, there is no way we can predict the size and timing of the next tsunami. For this reason people must maintain an awareness of tsunami risk, must be able to recognise the warning signs, and must locate houses and schools in safe areas.

The three warning signs are any strongly felt or prolonged earthquake, any unusual changes in sea level, and the roaring sound that many described as like a large jet engine.

We also distribute information leaflets that we print here at the University and, on the last two visits, copies of a small booklet on tsunamis provided by the International Tsunami Information Centre in Hawaii (ITIC).

The awareness program has been a success as far as it has gone, but there is still a need to combat the residual fear and uncertainty in people's minds.

The fear is partly derived from the memories of that horrendous night. Let's try to imagine what it was like.

They were confronted by a rapidly approaching wave 10 metres high, thrown bodily into a furious mass of swirling sand laden water, clothes ripped away, pummelled by logs, gashed by sheets of iron, and finally deposited in the lagoon or the fringing mangroves.

They recovered consciousness bruised and some in agony, called for help and searched for loved ones in the pitch darkness that followed the wave, made their way, naked, back to the sand bar that was once home, or through the mangroves and sago swamp to safer places inland.

Where their homes had been there were now bare house poles and debris. Every item of personal possessions, treasured or mundane, was gone. The loss of loved ones would become known only later.

Many waited for help through two long days while the helicopter from the Highlands Pacific - Cyprus Amax Frieda River mining exploration camp struggled to ferry the worst cases to safety. A second helicopter joined the rescue on the afternoon of the second day.

For many, help came too late for survival or too late for wounds to be successfully treated.

The memories of the terror and tragedy of those days will take a long time to fade and will affect the way people face the future. Counsellors will do what they can to help.

Working against the efforts of counsellors are some religious groups that are preaching about a bigger and stronger tsunami. This ridiculous talk adds unnecessary worry and fear where there is already more than enough to go around.

The fact is that noone can predict earthquakes and noone can predict tsunamis. We do not know when the next tsunami will happen nor where it will strike but, based on past history, it will be smaller than the Sissano tsunami and will strike some other part of the PNG coast.

Another factor causing uncertainty is that stories are circulating of a foreign plot, that the tsunami was caused by a bomb, and that the bombing is somehow connected to an underwater chasm at the mouth of the lagoon, a chasm that is said to have yielded finished timber, iron, wire and other goods to the people of Warapu in the past.

The story may sound crazy to you and me but it doesn't sound crazy to some of the survivors, so let's examine the bomb theory more closely

Theoretically it is possible. A large nuclear device can release energy equivalent to a magnitude 7 earthquake and, if triggered below the sea floor, could cause a tsunami.

Notice that the bomb would need to be in rock below the sea floor, not resting on the sea floor.

A bomb resting on the sea floor would cause an enormous vapour column and the familiar mushroom cloud, followed by radio-active fallout. No vapour column nor mushroom cloud were seen and no radio-active fallout has been detected. Strike One.If the bomb were to be placed below the sea floor that would require a hole to be drilled in the sea floor by a drill ship. Noone saw a drill ship in the area. Strike Two.

Finally, the shock waves from a bomb are quite different from the shock waves of an earthquake.

The explosion of a bomb will cause a compressional wave to travel out in all directions. At every earthquake recording station around the globe the first wave to arrive will be a compressional wave, a "push" rather than a "pull".

A naturally occurring earthquake will send a compressional "push" wave in some directions, and a dilational "pull" wave in other directions. At stations around the world the first wave to arrive will be a "push" at some stations and a "pull" at others.

This was the pattern that was caused by the Sissano earthquake. So we can be absolutely certain that this was a conventional earthquake and not a bomb blast. **Strike three - you're out!**

I'll repeat that just in case any doubt remains in anyone's minds. There definitely was no bomb explosion on the night of 17 July. The tsunami was caused by an earthquake.

The next stage of the information program is to produce better literature, perhaps something along the lines of the ITIC booklet, and a video tape that can be shown in the care centres.

A video tape has far greater potential to inform and reassure people than anything we have done so far. Perhaps Father Mlak and John Eggins will rise to the bait?

Talking about the tsunami with survivors from the Arop villages at Pou village care centre in August 1998
- the Orogen-sponsored public information program in action.
(Photograph courtesy Ms Gillian Hills and UPNG student counsellors.)

First map of the wave.

Earth Talk for 3 November 1998

Sissano Lagoon is a muddy brown body of brackish water flanked by mangrove swamps on three sides and separated from the sea by the sandbars where Warapu and Arop villages once stood.

For all that it doesn't look so great it is still a marvellous source of food, fish, shellfish, prawns, crabs. The lagoon was central to village life before the tsunami because it not only provided food for all, but also was a watery highway by which you could reach the family gardens or the sago swamps.

The lagoon used to be deeper and more open to the sea but in recent years has become shallower and the mouth more restricted so that the mixing of lagoon and sea waters is greatly reduced.

The shallowing was caused by the gradual build up of sediment brought to the lagoon by three small rivers and probably has been worsened by the great volume of sand that was carried in and dumped by the tsunami.

People in the care centres are keen to resume fishing in the lagoon but are waiting for the OK from health authorities. We hope analytical tests of all the lagoon creatures will begin this week.

Timing the tsunami

The lifestyle in the villages around the lagoon had many charms especially when compared with the lives we lead in the cities.Apart from getting the kids to school, there were few schedules to keep, no PM Vs to catch, no power cuts (no power!), no pokies, no raskols.

Watches and clocks did not rule the day and the honoured civil service custom of clock-watching became a forgotten art. Ah, paradise.

However, the relaxed attitiude towards time keeping makes life difficult for any poor fool of a outsider who comes around asking questions about the exact timing of a natural event such as an earthquake or tsunami.

He is likely to get all sorts of answers. Some say the 17 July tsunami hapenned at 5.30, others 7.30 pm, and most others somewhere in the middle at around 6.30 or 7 pm.

Fortunately for the befuddled questioner the world's earthquake recording laboratories are quite obsessed about accurately recording the time and so can tell him what time an earthquake occurred, to the very second.

He, in turn, can use this information to pin down the timing of other events such as the the tsunami. This is what today's story is about.

On the evening of 17 July seismologists recorded two earthquakes that originated in the Sissano area. The earthquakes were 20 minutes apart, one at 6.49 pm and the other at 7.09 pm, and the first was said to be the stronger and hence the most likely to have triggered the tsunami. Let's call the first EQ1 and the second EQ2.

Armed with this information one can then go and ask people in the Sissano Aitape area such questions as how many earthquakes did they feel, which was the stronger, and what was the timing of the arrival of the wave relative to the earthquakes?

Another good question is whether the wave arrived square on to the shoreline, or whether it came in obliquely, sweeping along the beach from left to right or right to left. One can confirm this by looking at the debris paths that the waves have left.

We can also look at damage and observe that the wave was at its most powerful in the area from beyond Arop Community School in the east to Ni mas village in the west (labelled "devastated" on the map).

Putting all this information together we can then, for the first time, reconstruct the path and timing of the wave. This is what is shown in the map. Remember, you saw it first in Earth Talk in The National!

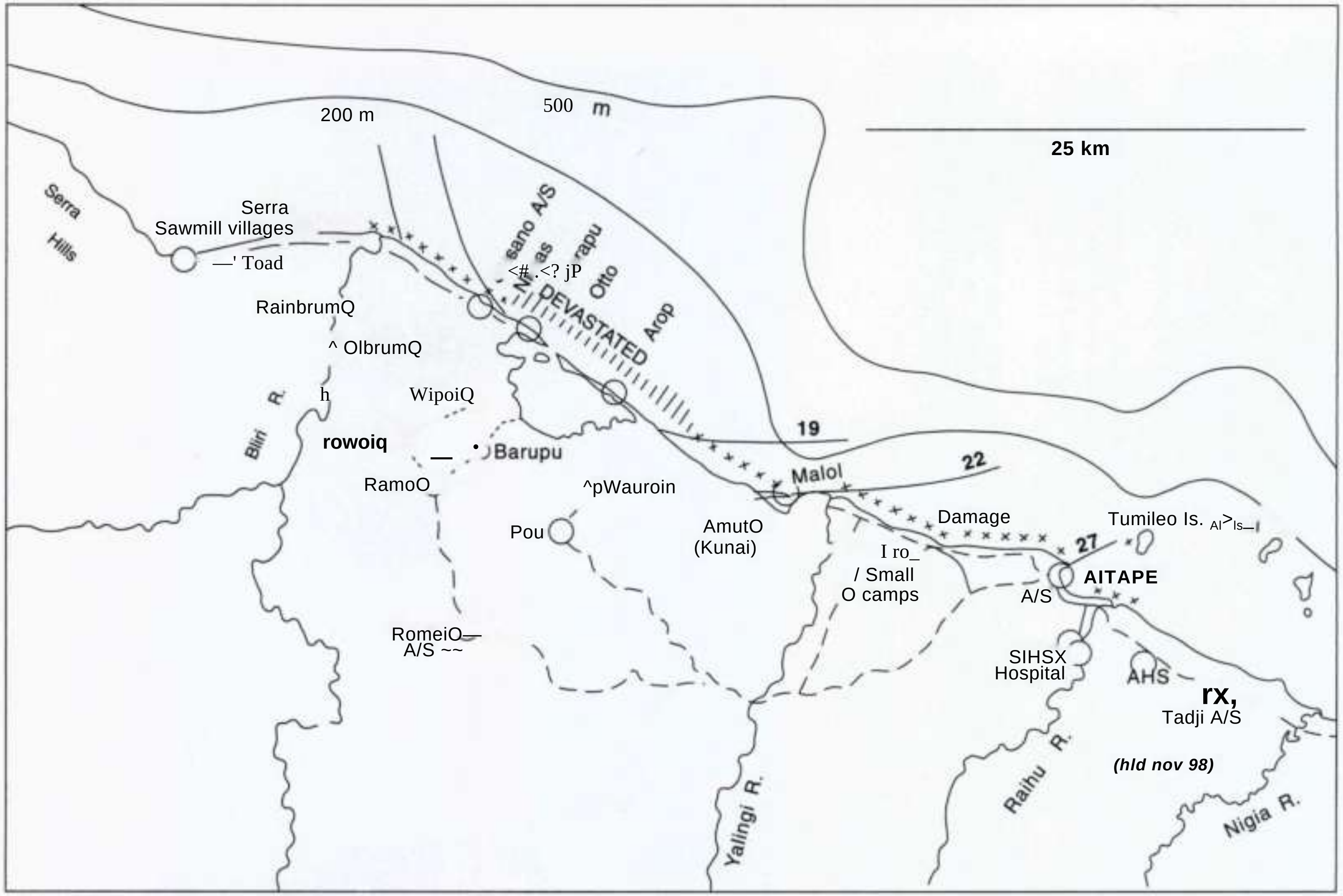
Here are some of the observations on which the map is based, just to show you how it was done.

Firstly eyewitnesses at Arop and Malol told me that in fact they felt three earthquakes, the first being a very weak shake about ten minuites before EQ1. This also was noted by Colonel John Sanawe at Arop. Let's borrow some jargon from the seismologists and call this first event a foreshock.

Survivors at Malol felt the foreshock, then EQ1, then EQ2. They said EQ2 was by far the strongest.

The first wave arrived at Malol immediately after EQ2 had ceased shaking. If we say EQ2 shook for two minutes then the wave arrived at Malol at time EQ1 + 22 minutes. The wave was square on to the coastline.

So we can draw a line parallel to the coast at Malol and label it with the number 22. Dickson Dalle, from his house is on a hill above Aitape, observed that the wave approached Aitape from the northwest, rather than the north, so we can add a gentle curve to the end of the 22 line.



The map shows the likely position of the first wave at 19, 22 and 27 minutes after the first major earthquake (6.49 pm). The villages of Arop and Warapu received the full brunt of the wave and were completely destroyed, as was most of Nimas. Other villages at Sissano, on the Malol beachfront, at Lampu and Teles east of Malol, and at Tarau Point (the mouth of the Raihu River) were partly destroyed. People from the western Sissano villages are now at Olbrum and Rainbrum; those from Nimas at Rowoi and Wipom; those from Warapu at Barupu; Arop No. 1 at Pou; Arop No. 2 at Wauroin; and most Malol people at Amut (Kunai). More than 10 000 people have been displaced and are still receiving food supplies. The abbreviations are SIHS Saint Ignatius High School (Year 12); AHS Aitape High School (Year 10); and A/S airstrip.

Eyewitnesses on Tumileo Island felt two earthquakes that were equally strong, EQ1 and EQ2. The wave arrived on the west coast of Tumileo five minutes after EQ2 so we can draw a line between Aitape and Tumileo and label it with the number 27.

Survivors from the "devastated" area between Arop and Nimas and westward to Sissano mission and airstrip felt only one earthquake. This suggests that the first wave arrived some time before the second earthquake, at perhaps EQ1 + 19 minutes or even as early as EQ1 + 18, or EQ1 + 17.

At Arop, Warapu and Nimas the wave was square on to the shore, but at Sissano Mission it was oblique, sweeping along the coast from east to west. So we can draw a curved wave front and label it with the number 19.

Yes it is a crude method, I agree, and involves some guesswork. But probably it is the best we can do.

Surprisingly, the shape of the wave front is quite similar to that shown in The Wave video tape. Perhaps Father Mlak had inside information!

Two more conclusions can be drawn from this map. First, we can estimate the speed of the wave by measuring the distances between the three wave front lines and dividing by the elapsed time.

The result is around 16 metres per second, which is not too far off the speed of 10 to 15 metres per second that was estimated by the international team, using other evidence.

The second is that from the shape of the wave front we can locate, roughly, the point that the tsunami started from. My guess is that this point was 20 km straight out to sea from the Otto mouth. What do you think?

At Vokau village, east of Aitape, the waves arrived obliquely from the west. Water 80 cm deep flooded in across former beach ridges to the edge of the village, 100 m from the present shoreline, then swirled westward and back to the sea.

Communications

The Sisters at Malol tried desperately to let the outside world know of the tragedy on the evening of Friday 17 July but were unable to make any contact until the scheduled Mission Radio Sched next morning. Better communications must be part of our planning and preparation for future disasters

The size and speed of the wave

Earth Talk for 10 November 1998

There are still many things we don't understand about the wave. For example, was the water hot and if so why? Was the water chemically tainted, as many people said? And what was the cause of the lights that many people saw?

And why was the wave much bigger than one would expect from a magnitude 7 earthquake?

Let's start with the question of the size of the wave. Just how big was it? Was this really a a magnitude 3 tsunami (maximum height 10-20 metres), or rather a magnitude 2 (maximum height 4-6 metres), or even a magnitude 1 (2 metres or less)?

Before answering the question we need to review some basic tsunami lore.

Firstly, as you know, a tsunami.can be triggered by any movement of the seafloor. The movement might be a sudden uplift of part of the seafloor due to movement on a fault, or to a submarine landslide, a submarine volcanic eruption, or the eruption of a mud volcano driven by gas and mud escaping from beneath the sea floor.

Once the tsunami is triggered the wave moves away from the source in all directions at a speed that depends on water depth. In deep water the tsunami will form a low wave that has a very long wavelength (a great distance between successive wave crests) and moves at great speed.

In shallow water the wave will slow down, the wavelength will decrease and the wave height will increase.

We can calculate the speed of the wave using a simple formula as follows: wave speed equals 3.1 times the square root of the water depth. For example, in a water depth of 100 m the wave speed is 3.1 x 10 = 31 metres per second (about 110 km per hour).

As a wave approaches the shore its speed will decrease to 15 metres per second in 25 metres water depth, and to ten metres per second in ten metres water depth.

Thus where the sea floor slopes gently up to the beach, the wave is forced to slow down, the wave length decreases and the wave height increases proportionately.

Conversely, where the sea floor slopes steeply, the wave will not slow down, the wave length will not decrease, and the wave height will not increase.

So it is very clear that the height of the wave is determined by the shape of the sea floor.

Now let's return to Arop and Warapu.

We know that the breaking wave at Arop and Warapu reached heights of 10 to 15 metres, which is about the height of a mature coconut palm or a three-storey building. It's the kind of giant wave that you sometimes see in surfing movies from the north coast of Oahu or in the blue water off the coast from San Francisco.

We could say the 10-15 metre wave indicates a tsunami of magnitude 3. But does it? Is this a true measure of the magnitude of the tsunami or is it, rather, an anomalous effect caused by the shape of the seafloor?

If we agree that it is an effect of the shallow slope of the sea floor then the true size of the tsunami, for the purpose of determining magnitude, is somewhat less. How much less is a more difficult question.

Probably the international team will have some answers, based on their survey work. My very rough estimate, based on the water marks left on some of the buildings at Sissano, is that the overall height of the wave at Sissano was three to four metres above sea level and thus the tsunami at Sissano was magnitude 2.

Even so the tsunami is "too big" to have been caused by a magnitude 7 earthquake. Such an earthquake should cause a wave of 1-2 metres height at most.

Could there have been a secondary effect such as a submarine landslide or mud volcano that boosted the size of the tsunami? We should know the answer after surveys of the sea floor are carried out in the new year.

One line of evidence that suggests that there may have a secondary event is the timing of the wave.

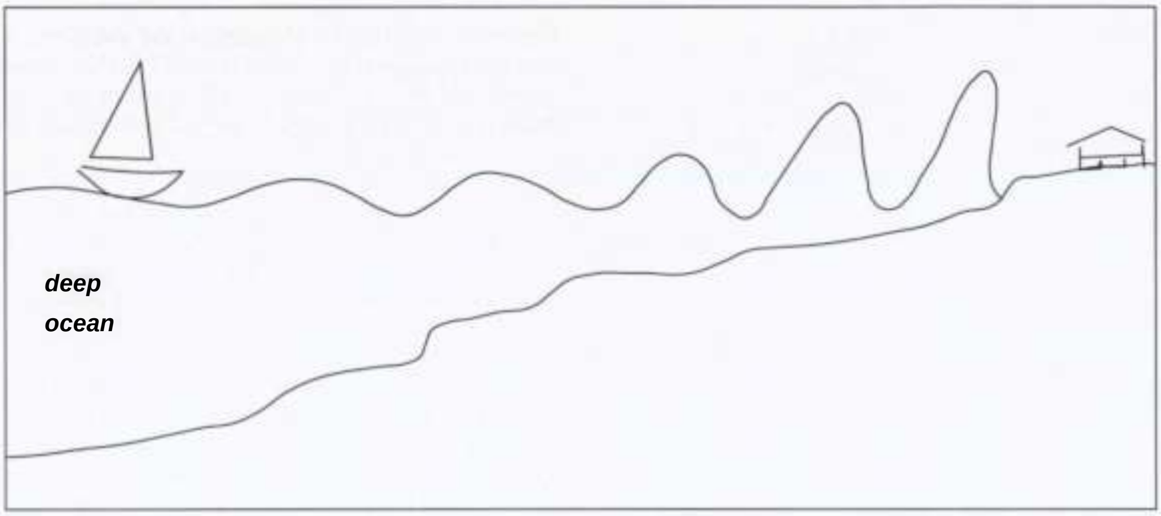
Using the wave speed and water depth formula we can calculate that a wave that originates in 500 m water depth at a distance of 20 km from the coast should reach the coast within ten or eleven minutes.

However, from the evidence discussed last week we believe the wave reached the coast 17-19 minutes after the earthquake. Thus, it arrived six to nine minutes later than we would expect.

This could be an indication that the wave was triggered not by fault movement associated with the earthquake but, rather, by a landslide or mud volcano that followed some minutes after the earthquake.

On another topic, many survivors reported that the water in the waves was warm. Some have suggested that this was evidence of volcanic activity but I doubt this is the case. There were no other signs of volcanic activity and even if there were volcanic activity at a distance of 20 km it could hardly warm the water near the coast. Similarly, the escape of a great volume of hot gas could cause warming of the water column above the gas vent. But would we expect the warming effect to prevail as the wave was transmitted through water some tens of kilometres away from the gas source. It seems unlikely.

Some reliable observers have recounted that all three waves broke as they approached the shore. rather than arriving unbroken then crashing on the villages. In this case the warming could have been caused by the release of a great amount of frictional energy as the turbulent water of the broken wave, with its load of suspended sand, surged toward the beach.



While a tsunami wave is in deep water it travels at great speed, has a very low amplitude, and a very long wavelength (the distance between the crests of two waves) In deep water the tsunami could pass beneath a canoe or ship and noone would notice.. However, as the wave enters shallow water the speed of the wave slows down, the wavelength shortens, and the amplitude or height of the wave increases.

Where the wave crashed down on the houses of Warapu village the turbulence destroyed the houses, ripped out and removed the house posts, and excavated the soil beneath the houses to depths of 2-3 metres.

What can be learned from the damage?

Earth Talk for 17 November 1998.

The Sacred Heart church at Sissano was built by German SVD missionaries in 1926. It was built on a grand scale and seated more than 1000 people. The walls were of timber and locally-made cement breeze blocks and the two-tiered roof was of corrugated iron.

The church survived the massive earthquake of 1935 and the very strong earthquake of 17 July 1998 with only minor damage, but did not survive the tsunami. Today only the concrete floor remains.

On the afternoon of 17 July David Monana of Nimas was sitting on the tractor near the church when he felt the unusually strong earthquake. Statues in front of the church were broken and David's mother called to Father Otton Ratazchek to inspect the damage.

Father Otton walked the 40 metres or so from his house and together they entered the church to clean up. The shaking caused some damage to a roof brace and some cracking of the walls, so after cleaning up they went outside again for safety.

Father Otton returned to his house but after a while heard a strange noise from out to sea. He left the house and walked towards the beach to investigate but was met by his catechist, running at top speed and calling out a warning about a big wave.

Together they ran away from the sea towards the boat landing on the lagoon. Behind them the waves broke on the beach flattening a grove of 30-year-old coconut palms. The water swept through the mission station carrying all before it.

First to go were the sisters' quarters, a community hall and Father Otton's house, which were nearest the beach, then a workshop shed and then the church.

The clinic building, which is off to one side, survived the wave with some damage. It seems to have received a less energetic attack, perhaps because it is partly protected by trees. Marks on the walls of the building show that the water reached two metres above ground level.

A wood-frame two-storey classroom building near the church was lifted bodily and floated 55m southwestward where it collided with a grove of coconut palms. The lower walls gave way and the top storey classrooms settled to the ground

Curiously at about this point the surging water lost its momentum. Trails of debris and hollows that are still filled with water show that the water turned westward and flowed more passively along the hollows between old beach ridges and eventually out to sea.

Father Otton and the group that had gathered with him at the boat landing were saved. Water came through to the boat landing but was below knee height.

Houses near the boat landing and northward to the road and westward to Maindroin and the airstrip were undamaged.

Although the worst seemed to have passed and many houses were intact, the group were unsettled by the continuing earth tremors and fearful of another wave.

They took boats and headed a kilometre inland to the hills at Olbrum, where they camped for the night.

Meanwhile David Monana, upon hearing the noise from the sea, parked the tractor in its shed and ran east along the road towards Nimas looking for his wife who was full term with child, and their two young children.

Before going far he was met by a fast-flowing surge of water one-and-a-half to two metres deep and was swept backwards into the lagoon. By this time it had become completely dark.

Abandoning hope of finding the family he started swimming towards a weak light that he could see in the distance. The light, he learned later, was Father Otton's torch at Olbrum.

David reached Olbrum late that night. His wife survived and their son Emmanuel was born two days later. Sadly one child did not survive the tsunami.

Lessons for the future

The story at Sissano mission was repeated at other Sissano villages. In some places everything was destroyed but in others houses survived intact. Only at Warapu was demolition complete.

Why was this so? What were the factors that saved some areas and not others?

If we can find the answers to these questions then we are part way towards reducing the risk from future tsunamis not only here in the Aitape district but also in other coastal villages in PNG and the southwest Pacific.

There are some obvious and long recognized factors. For example, offshore islands and reefs help protect the coastline by dispersing the energy of the wave.

Also, if the sea floor slopes steeply from the coastline the wave will not form a giant breaking wave but rather will arrive in the less destructive form of a rise and fall in sea level.

Another factor is that if villages are on high ground or are some distance from the water's edge then they are unlikely to be badly affected by the wave. This is old stuff and obvious. From the evidence at Sissano what can we say that is new?

1. We can observe that, for no obvious reason, the wave had more energy in some sectors than in others. Perhaps this is something to do with the shape of the sea floor immediately offshore. This is hard to prove and difficult to use as a guide.

2. Of more practical use is the observation that at different locations thickets of trees provided some protection. The minor scale of damage at the Sissano clinic probably was due to both a less energetic attack by the wave, but protection by trees may have been a factor.

3. The wave normally will lose energy as it progresses inland. Structures that are more than 800 m from the beach are almost certainly safe, and structures 400 m from the beach are reasonably safe. However there are exceptions, as we will discuss next week.

Certainly at Sissano mission there was reduced damage beyond 400 m, where buildings south of the road were undamaged. Similarly at Nimas, despite the massive and widespread destruction of most of the village, three or four houses 400 m from the coast were spared. These house were partly protected by trees.

We continue next week with some new ideas on the importance of the shape of the land surface and the value of drainage channels.

BELOW: The map shows the pattern of damage at Sissano Mission and the path taken by most of the water **(arrows).** The wave broke on the beach and flattened young coconut palms, then swept southwestwards across the open ground of the mission destroying the priest's and sisters' residences **(Fr, Sr),** the church (Ch), an adjacent cement-block water tank, and a storeroom. A one-and-a-half-tonne tractor **(Tr)** and a classroom building (the western Cl) were transported 60m to SW. The clinic (+) was damaged but left standing as water 2m deep swept through from the northeast. Most of the water then flowed westward into gullies north of the airstrip **(A/S)** leaving the houses of Mainyar and Maindroin undamaged. Survivors who had gathered at the boat landing (B) were unhurt.

ABOVE: The 76-year-old Sacred Heart Church at Sissano, looking east. Photograph by Fr Eugene McKinnon OFM

BELOW: All that remained after the wave was a broken statue, a concrete slab and debris. Two sets of classrooms are in the distance. The view is to the south, August 1998.

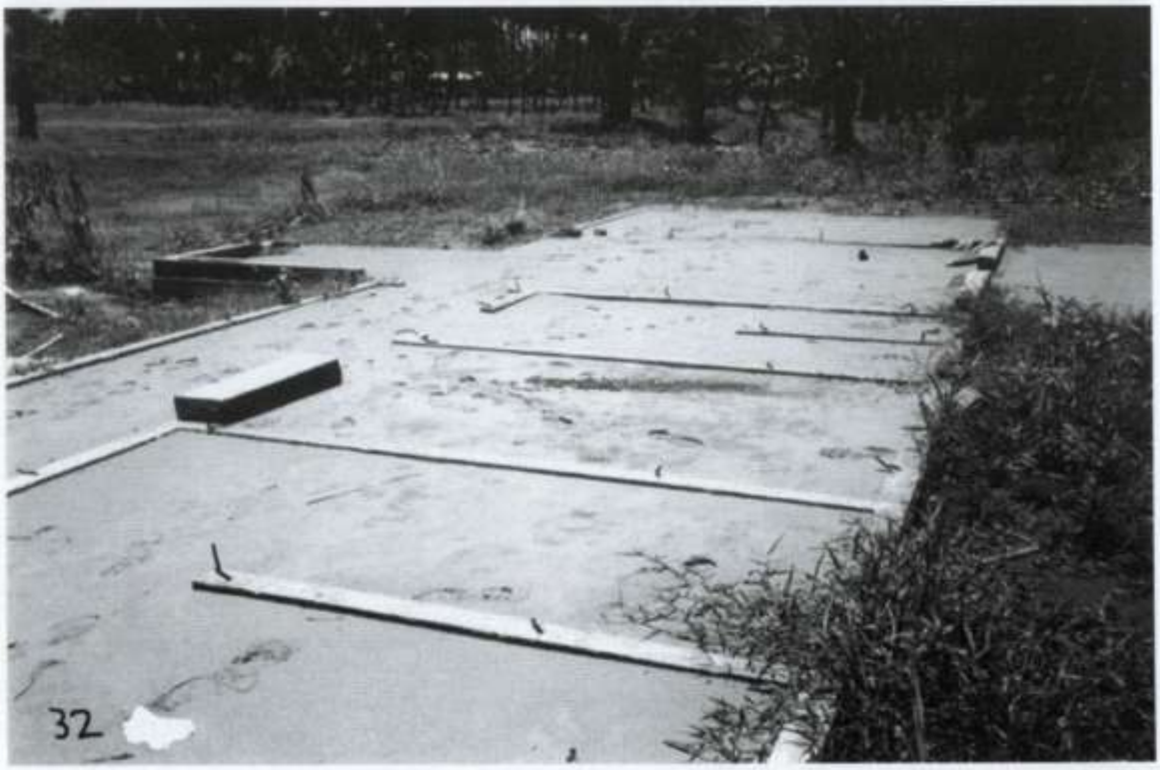
The interior of the Sacred Heart Church at Sissano, Father Eugene McKinnon officiating. Photographs from the collection of Fr McKinnon.

ABOVE: The class photograph by Fr McKinnon shows the two-storey classroom building on the left and the priest's house in the distance. The view is to the north.

BELOW: The two-storey classroom building was transported 55 m by the wave and came to rest against coconut palms (left). The lower storey of the building collapsed. The view is to the west, October 1998.

ABOVE: The priest's house at Sissano was built in 1972. The view is to NNW from near the church. Photograph by Fr McKinnon.

BELOW: After the wave only the concrete slab remained. The view is to the west and was takenin November 1998, by which time the grass and some flowers had recovered.



Smoking crab holes

Earth Talk for 24 November 1998

On my first visits to Aitape the sole objective was to reach out to the people with information about the tsunami, explaining what had happened and discussing the outlook for the future.

On the later visits there was time to examine and record the damage and to look for the reasons that some places were more badly affected than others. Last week we presented three conclusions from this work.

Firstly, the wave seemed to have more energy along some parts of the coast than it did in others. Probably this has something to do with the shape of the sea floor immediately offshore.

We've asked the Defence Force Civic Action Committee to initiate a near-shore marine survey to look into this.

Secondly, thickets of trees and shrubbery provided some protection by absorbing some of the energy of the wave, by catching and holding logs and other debris, and by diverting the water to one side or the other.

However, the groves of well-spaced coconut palms had little effect. In fact they may not have slowed the wave at all.

Thirdly, after the waves had travelled 300-400 m they tended to lose energy and so cause less damage. This is a rule of thumb that is widely accepted overseas, but not alwys true, as we discuss further on.

This week's set of conclusions is to do with the effects of slopes, humps and hollows in the land surface. Continuing from last week, we start with conclusion number four.

4. Along most sandy coastlines there is a ridge or berm at the back of the beach that stands one to two metres above high water mark (see illustration). The berm is made up of sand that has been piled up by storm waves. Most berms have some grass or shrubs on top, and a low cliff towards the sea.

A high berm will provide more protection from a tsunami wave than will a low one. The berm at Sissano mission and at Uyang (Big Malol) and Lampu and Teles is so low that it is almost awash at high tide and thus provides little protection.

The berm at Nimas and Warapu is higher at l-2m but would pose no more than a slight hiccup to a 10m wave.

5. Once the wave crosses the berm and moves inland it may encounter obstructions or undulating ground in which case it will start to lose energy.

However, if the ground behind the berm is clear of obstructions and has a downhill slope, as was the case at Warapu school, Nimas and Sissano Mission, the wave will keep all its energy, and may even gain momentum.

Similarly in the villages of Big Malol, Lampu and Teles the ground slopes downward away from the sea. The result is greater damage than might otherwise have been the case.

6. If the ground behind the berm has very low relief and is swampy with only sparse vegetation the wave may continue with great energy for a distance greater than the rule-of-thumb 400m limit.

An example is the area between Arop Community School and the coast (see pictures), where the wave advanced with great power as far as 500 m from the shoreline, reaching the very perimeter of the school.

The wave uprooted and transported all in its path, coconut palms and 30-m trees, and left a sterile, pock-marked land surface. If you want to go to get a feel for the power and fury of the wave then this is a good place to start.

7. Small undulations in the land surface are a safety factor. If your house is on a small knoll, say one metre higher than the surrounding area, then it is more likely to survive a surging wave than if it is on flat ground or in a hollow.

Similarly if your house is built on high, strong, firmly-planted house poles then it is more likely to survive than is a house on 60-cm stumps, or a house on high stumps that are not firmly planted.

8. The advantage of living on high ground is obvious. Less obvious, perhaps, is the advantage of having some natural drainage channels nearby, such as small gullies and hollows.

For example, parts of Uyang (Big Malol) were preserved because once the water reached the village it was deflected to one side, following a gully that led to the lagoon.

Similarly at Sissano the water flowed off to the west into the hollows north of the airstrip, leaving Maindroin undamaged.

9. Finally, and perhaps most obvious of all, houses that are close to the shoreline are at greater risk than houses some distance inland.

The evidence from Warapu and Arop is that houses within 100 m of the shoreline (measured from the front of the berm) may be hit directly by the full downward force of the wave as it curls and breaks.

Houses that are further from the beach, but still closer than 400m, may receive the full horizontal force of the wave, unless protected by landform or vegetation.

For the next stage of this study I have in mind a tsunami hazard score sheet, a series of questions that can be used to estimate the tsunami risk for each coastal settlement; and to put forward some ideas on tsunami protection.

Let me finish off with a tsunami story that was told last week by Schubert Rainbubu of Nimas as we walked through the sand scours and debris that are all that remains of Warapu.

It happened that at some time in the past the ancestors lived in houses that were built of limbon palm. The palm poles, which are very strong, were firmly planted in the ground.

The houses were roofed with saksak leaves and these in turn were overlain by pandanus leaves to provide extra protection from falling arrows. The houses were very strong and were referred to as nolelei.

One day there was a great tsunami. A man and his wife saw the tsunami coming and climbed coconut palms in order to escape the wave.

After the wave had passed they looked down and saw that the ground was completely covered in wet sand.

They were concerned that the wet sand might not support their weight so, rather than climbing down right away, they cut a coconut and dropped it. The coconut disappeared into the wet sand without trace.

They waited a while then dropped another coconut. This too disappeared into the wet sand, but more slowly than the first.

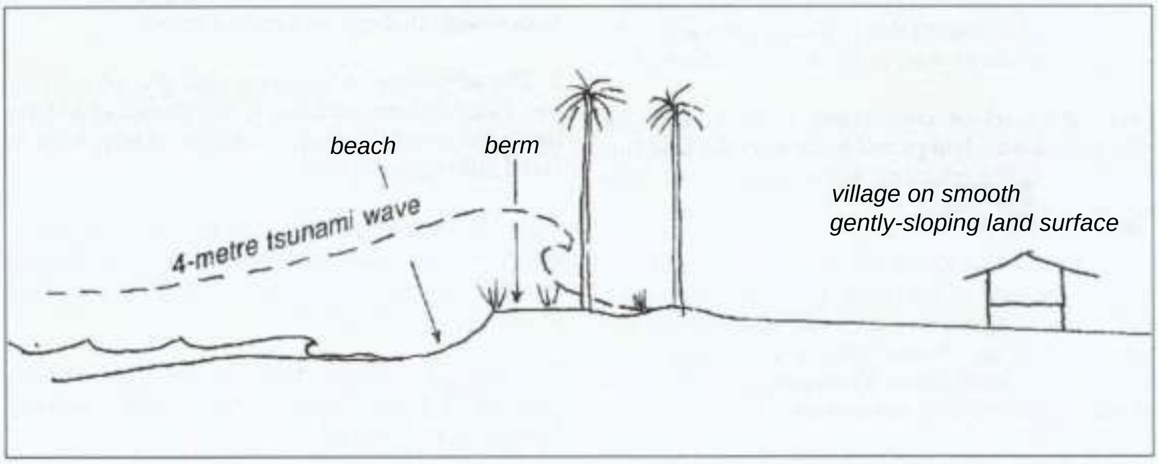
They waited some more then dropped a third coconut. This one hit the ground with a thud and did not sink in at all. So they knew it was safe to climb down.

When they reached the ground and looked around they noticed one very strange thing. There were many crab holes in the sand and from some of the crab holes smoke was rising.

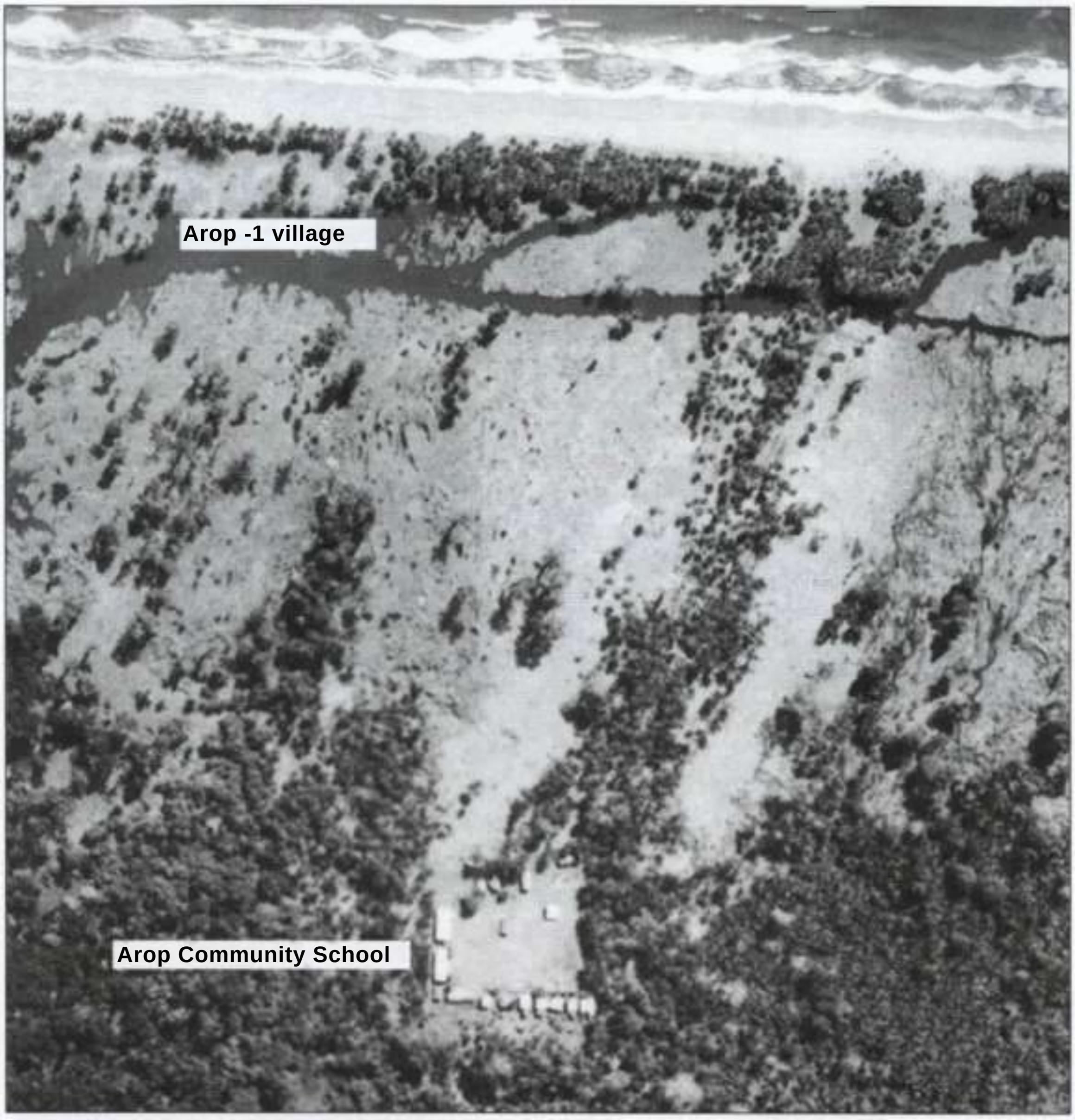
Very puzzled by this they started to dig into the ground around the smoking crab holes. Before long they came upon the pandanus leaf roof of a nolelei house. They made a hole in the roof and pulled out the people who had been trapped inside the house.

This small group of tsunami survivors went on to found the Sissano villages.

(My apologies to Schubert for errors and omissions.)



The berm or ridge at the back of the beach and the grove of coconut palms have little effect on the advancing wave. However, thickets of trees and shrubs will slow the wave and will trap debris such as logs and timber. If the village is on rising ground the wave will lose speed and energy and damage will be reduced. On the other hand, if the village is on a land surface that slopes downward away from the sea the wave will gather speed and cause greater destruction.



An aerial photograph illustrates the destructive path of the wave across swampy forested land at the eastern end of Sissano Lagoon. Coconut palms near the beach were undamaged but tall trees and coconut palms further inland were tom from the ground and stacked like driftwood as the wave surged for 550 m to the perimeter of Arop Community School. Photograph reproduced by courtesy PNG National Mapping Bureau.

WWW

The investigation of the Aitape tsunami by scientists around the world provided an illustration of the power of the WorldWideWeb. Except for the marine investigations there has been a free flow of information and ideas between scientists. The First ITST posted their preliminary report on the Web within a month of completing their survey. We posted the results of our investigations as they were completed, including the maps that appear on pages 27 and 32, and overseas scientists could follow other developments in the two national newspapers, on the Web. We continue in almost daily contact with experts in Japan and the USA as the investigations proceed, being given advice and in turn providing information.

ABOVE: Logs and other debris transported by the wave are piled against the western classroom at Arop Community School. The building was not damaged.

BELOW: A view from near the school looking back towards the beach shows how the ground was stripped bare by the wave. The water-filled hole marks where a tree was uprooted. In the distance, coconut palms on the shoreline are undamaged. Both photographs were taken in September 1998.

A Tsunami Score Sheet

Earth Talk for 1 December 1998

As the end of the year approaches we like to look back at the events of the past year and to look ahead at what the new year may bring, imitating the two-headed Janus.

For our two major universities the current year has been difficult, especially here in Port Moresby where we coped with a late start, power rationing, and a student strike - but 1999 is likely to be much tougher.

It will be tough because funding from the national government has been reduced by 20 percent. In the case of UPNG that means there is not enough money to pay staff salaries, let alone to meet other running costs.

It would be a little bit of paradise to have just one year with no external problems when we focus solely on our task of training the nation's young people! Dreams, dreams ....

Looking back at 1998 it is hard to see beyond the Aitape tsunami. It was a monumental event and dominates the horizon.

In terms of death and injury it ranks second to the 1951 eruption of Mount Lamington in the modem history of our islands. In terms of shock and terror the two events rank equally, for both were completely unexpected and burst upon a peaceful and unsuspecting rural population.

They say that each American can recall exactly what he or she was doing at the time they first learned of the assassination attempt on President John F. Kennedy.

I was studying in California at the time and can vouch that this is certainly tme for myself and for the dear meri bio mi.

The Aitape disaster was a bit like that too, although the impact of the news was diluted as we first heard that maybe six were dead, then perhaps a few more than six. For most of us the true horror of the event was only brought home 48 hours after it happened, on the Sunday evening.

For me Aitape became a personal thing. Something inside said I had to be there helping out but the brain said Whoa, it's not your job, and apart from that you have classes to teach.

Then through the wonders of the internet I learned from Jackson Rannells in California that the international team was planning to visit to record the damage. I made contact with them and set about doing what I could to clear the way for their entry into PNG and into the disaster area.

To cut a long story short, the international team came, did a very professional job, and in passing gave me the impetus and background information that I needed to get out there amongst the survivors. Their expert advice and their encouragement of the awareness program continues.

For everyone who lives near the coast in our islands Sissano was a reminder of vulnerability. The disaster should be a stimulant, if such is needed, to put safety measures in place in all coastal communities.

Perhaps in the new year leaders from around the country can come to Sissano to walk through the damaged areas and see for themselves what worked in the way of protection, and what didn't.

The tsunami score sheet

I promised a tsunami risk score sheet for this week. It's a bit rough and ready but here goes. Low score means low risk and high score means high risk.

Firstly, if you live on the south coast of the PNG mainland, anywhere from Suau to Morehead, the tsunami risk is low. Score zero for risky location. All others score at least one.

Secondly, if your shoreline is open to the ocean, with no fringing or barrier reefs, and if at times of the year waves of one or two metres height break near the shoreline, then the risk of a damaging, breaking tsunami is high. Score at least one.

Thirdly, if from time to time you feel earthquakes, or if there are volcanic islands in your area, score at least one.

If your score is now greater than zero, here are some more questions.

If your village and key buildings (hospital, school, church, power station, telephone exchange) are less than one metre above maximum high tide level, score lots.

If they are more than 10 m above maximum high tide score zero, if 5 m score one.

If the village and key buildings are less than 5m above maximum high tide level, and are within 100 m of the shoreline, score two.

If they are 400 m from the shoreline score one, and if 800 m score zero.

If you scored more than zero on any of the last set of questions, continue.

If your house and key buildings are on a concrete slab that is at ground level, or are on stumps that are less than one metre high, or are not firmly planted, score two.

If the house or building are on high, firmly planted poles (say 2m poles) score zero or one.

If there is a thicket of trees and undergrowth between your buildings and the beach then you can reduce your score by one, because they will slow the wave and catch the debris.

However, if the trees or palms are widely spaced, don't subtract anything. They will be of no help.

If the trees or palms are standing on low-lying swampy ground and thus are not firmly rooted score two, because they probably will be uprooted and come hurtling your way on the wave.

If you live on, or visit, the coast and have not given any thought to the warning signs of a tsunami, and have made no escape plans, score five.

If you know the warning signs, and have a plan, and have impressed both on your neighbours and children score zero and take a bow !

At Nimas a thicket of trees trapped some of the logs and debris that were being carried forward by the wave. Houses behind the thicket were protected by the log jam and were undamaged. Almost all other houses in the village were destroyed, most without trace. Planting robust trees such as calophyllum or strong flexible trees such as casuarina along the waterfront is one way to obtain some protection from tsunamis.

Tsunami stories

If you want more information about tsunamis see the informative article by Frank Gonzalez of the United States NOAA Pacific Marine Environment Laboratories in the May 1999 issue of Scientific American magazine. Frank, with Mike Blackford of the International Tsunami Information Centre in Hawaii, has been generous with advice and information to PNG scientists and public since the July 1998 tsunami. You might also try the book TSUNAMI! by Walter C. Dudley and Min Lee, University of Hawaii Press, 1998.

The Odyssey of the Barupu

As a newcomer to the area, as I am to Aitape, it is a little bit dangerous to pretend that one is an expert, so please accept that whatever I write here may be some points to windward of the true story.

I haven't taken the time to check out these stories with the professional historians. If you live in the fast lane something has to give! That being said, let's get started, because it is a quite remarkable story.

Firstly, we know that the Barupu people migrated from Irian Jaya perhaps 300 years ago and that they settled first near Wutung then Vanimo.

From Vanimo they moved to the Sissano area in the 1850s, where they settled on two islands in the middle of a river that flowed to the coast between the present Sissano and Arop. At that time there was no large lagoon.

After the arrival of German SVD missionaries at Tumileo in 1896 there was intermittent western contact. Young men were recruited for plantation work in Rabaul and Alexishafen, and some were educated at Vunapope.

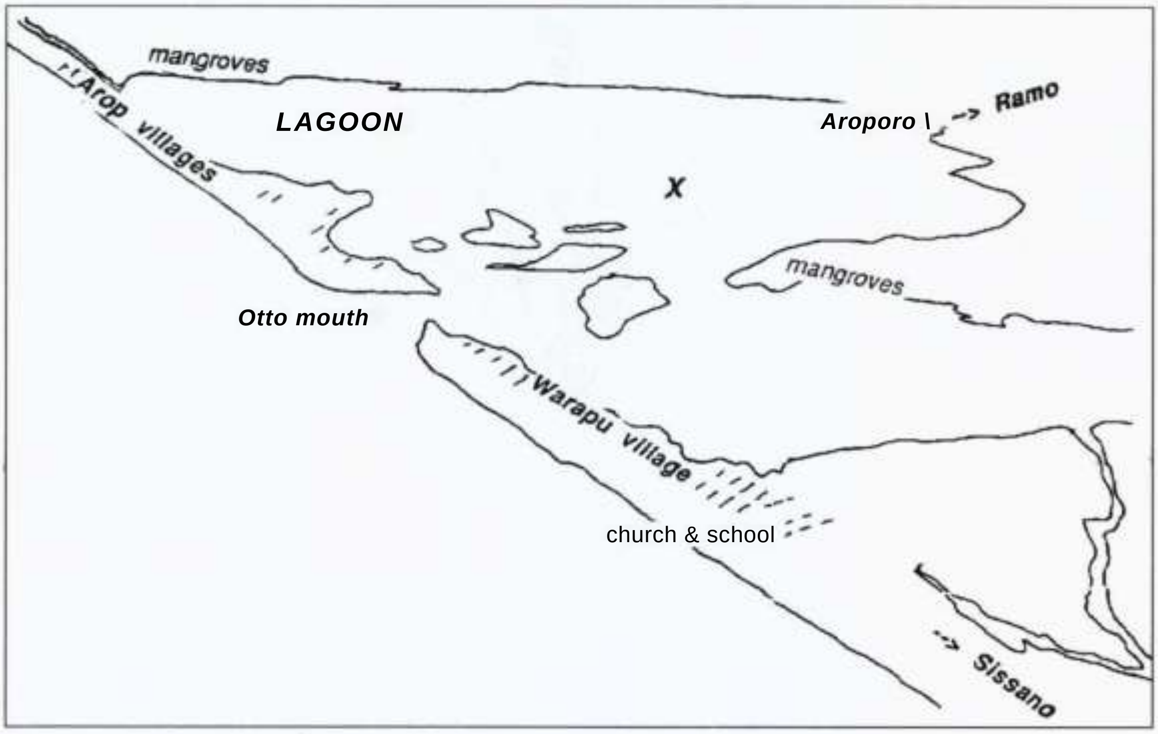
During the night of. 15 December 1907, at the time of a major earthquake the islands occupied by the 2000 Barupu begun to sink slowly. The subsidence continued until only the roofs of the houses were showing. This was the subsidence that formed what became as the Sissano Lagoon (known as Warapu Lagoon in those days).

There was sufficience time for the people to escape and to make their way to safety. No Lives were lost, not even the lives of pigs and dogs.

The people resettled at Aroporo (see map) and at other small hamlets on the perimeter of the lagoon. In 1932 SVD missionaries joined them at Aroporo. A fine church was built on the eastern side of the river and a government station on the opposite bank.

In 1937 the church burned down accidentally and soon after the people moved again, this time to the beachfront at Warapu. When the Pacific war reached this sector of coast in 1942-44 the people retreated inland, returning to the coast after 1944, Here they remained until the night of 17 July 1998.

The Barupu are now re-building again, at a new Barupu located just inland from their old home at Aroporo. Let's hope that this may mark an end to their journeying.



The map is an oblique view southward across Sissano Lagoon. X marks the spot where the Barupu villages stood before the ground subsided in 1907. When their village was flooded by the new lagoon the 2000 people moved to Aroporo and, 30 years later, to Warapu. The tsunami of 1998 destroyed the two Arop villages, Warapu and Nimas (near camera, not in picture). Survivors are now establishing new villages inland. The Warapus are re-building at Barupu, just inland from Aroporo on the track to Ramo.

Early photographs show the sunken village from which the Barupu escaped in 1907, and trees that were drowned by the same event. The photographs are from R. Neuhauss, DEUTSCH NEU-GUINEA (Berlin, Dietrich Reimer, 1911).

Scenes of Warapu village as it was before the tsunami. At top is the canoe factory, near the Otto Mouth. Today none of the houses and few of the trees remain. The photographs were taken by Mr Fred Terry in 1991.

The Warapu church (top),built in the 1960s, was swept away by the wave leaving only the bare concrete slabs (below). The top photograph is from the collection of Fr McKinnon.

What's new in 1999

To get straight to the point, we still do not know exactly what caused the tsunami. But many people are working on the problem. Perhaps by year's end we will know.

All of the experts agree that the tsunami was not a man-made event, and all agree that it originated with the magnitude 7 earthquake of 6.49 pm on 17 July 1998, but beyond that opinions differ.

Was it caused by movement of the seafloor on a fault at the time of the earthquake, or by a major submarine landslide, or by an explosion of highly-pressured gas on the seafloor? We don't yet know.

The best way to find the answer to these questions is to look for the evidence on the seafloor.

The Japanese Government has been active in this search for evidence. This is their way of helping PNG, but it also can help Japan (and other nations) because studies here in PNG can lead to a better understanding of tsunamis in Japanese waters.

The first Japanese ship to arrive was the research ship Kairei, in early January. In two weeks the Kairei and her crew of sailors and scientists mapped all of the seafloor from Aitape to Vanimo, in a strip that runs from near the coast to the 4000-m deep waters of the New Guinea Trench.

They also collected cores of seafloor sediments and used other methods (high-resolution seismic reflection) to look into the top layer of sediments on the seafloor in a few places.

In late February a second ship arrived. This was the submersible mother ship Natsushima, carrying the remotely-operated unmanned submersible Dolphin 3K.

The Dolphin 3K is like a very small submarine but with noone inside. It can be sent to the seafloor to take photographs and video pictures of the seafloor, and to collect rock samples using its mechanical arms. It is controlled by radio commands from the bridge of the Natsushima mother ship.

The submersible moves slowly and cannot see very far in the pitch darkness of the deep ocean, so we need to select targets carefully. The shipboard scientists chose their targets from features they could see on the seafloor maps produced from the Kairei cruise.

The results from both cruises were reported in Port Moresby at the end of each cruise.

What did they find?

The seafloor map produced on the Kairei cruise shows a broad shallow shelf offshore from the Arop-Warapu-Sissano coast. There are no obvious areas of weakness on the shelf and there is no indication that the shelf is unstable.

Immediately offshore from the mouth of the Yalingi River the shelf is cut by a major submarine canyon that carries sediment from the Yalingi River down the slope and into the New Guinea Trench. This was new knowledge, though we had surmised that such a canyon might exist (Earth Talk of 28 July 1998).

Most major PNG rivers have similar submarine canyons. Perhaps the best known example is the Markham Canyon offshore from the Markham River near Lae.

Beyond the broad shelf there is a slope that drops away towards the New Guinea Trench. The slope is broken by many steep-sided hills and hollows, most of which probably were shaped by movement on faults.

It was these fault-bounded hills and hollows that caught the eye of the shipboard scientists and this was where they pointed the TV cameras of the Dolphin submersible.

The pictures that they brought back of steep rock faces and gently-sloping silt-covered seafloor, and of strange sea creatures (at least strange to me), were quite amazing in their content and clarity.

The pictures did show evidence of recent rock falls and did show steep rock faces that doubtless had formed by faulting. Could these have caused a tsunami?

They concluded that the rock falls were hardly of large enough volume to cause a tsunami, and that there was no clear proof that the faulted rock faces had moved as recently as last July.

Probably they had not found the source of the tsunami. This was not too surprising given that there is such a large area to explore.

Also, the seafloor mapping method used by the Kairei was not the best for this purpose, in that it was a rather coarse-grained method, with a definition of 100 m. By this we mean that it could not see features that are less than 100 m across.

So it could not discover possible fault scarps or landslides or gas blowout structures that were on a scale of ten metres or several tens of metres.

Other work

The American research ship Maurice Ewing, with Prof Eli Silver in charge, will spend two days in the search area in August, running high resolution seismic lines in what are judged to be the most likely locations. Eli is well known in PNG.

Apart from this we are still hopeful that the Australian Navy might take up the challenge to map the shallower seas, inshore from where the Kairei worked. This is a likely area for gas blowout structures, and the Australian mapping system probably has sufficiently high resolution to detect these.

At different centres around the world computer modellers are working with the new seafloor map produced by the Kairei. Their major finding has been to demonstrate that the deeper waters of the Yalingi Canyon, where it cuts back into the shelf, would serve to focus the energy of the wave.

This they see as a possible answer to the question of why the tsunami's energy was so focussed on a short section of coast.

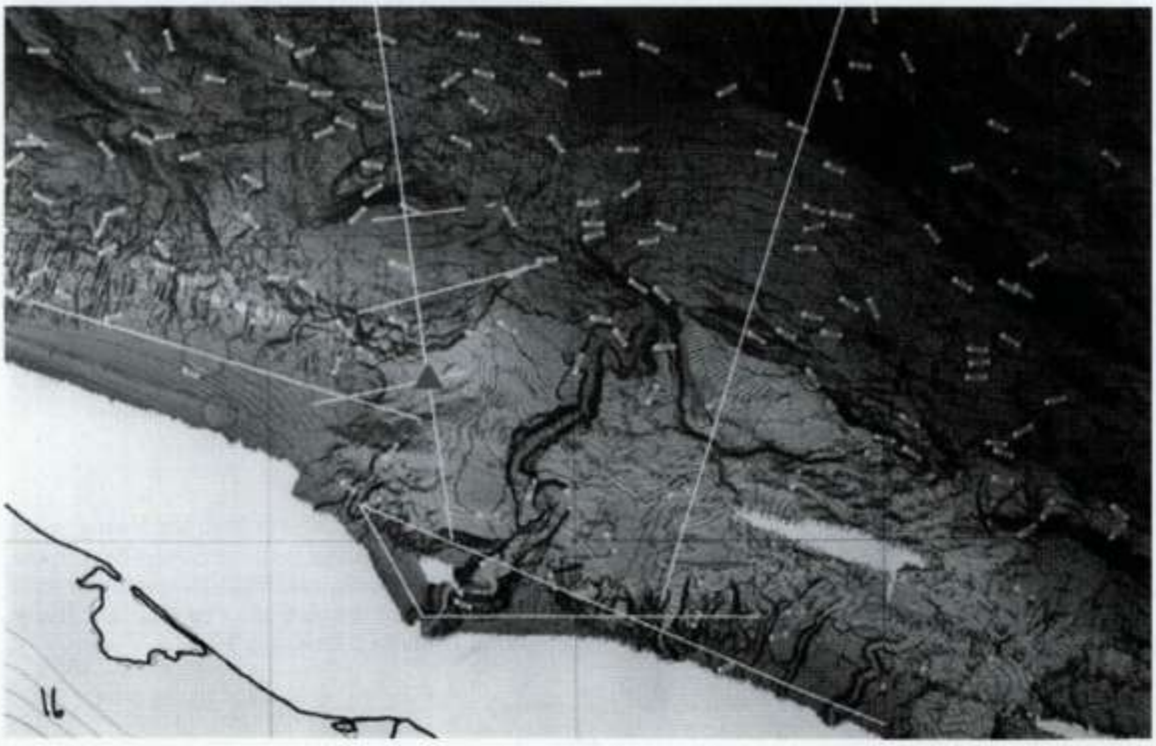
Meanwhile we in PNG continue to gather and collate information from survivors. From the outset this has proven to be a rich source of information.

Through some sort of oversight access to the data collected on the two Japanese cruises has been limited to a small group of scientists in Japan, the UK, USA, and Fiji, and not to scientists in PNG. We expect this anomaly will be resolved soon. The important thing, as we see it, is for all the scientists to pool their resources and work together openly and cooperatively to solve the problem of what caused the tsunami.

Beyond that we need to educate the public about tsunamis and to set in place emergency plans and procedures so that the next time nature strikes we are better prepared.

Left: The Japanese Chief Scientist on the two 1999 research cruises, Dr Takeshi Matsumoto, explains a point at a media conference in Port Moresby.

Below: Part of the map of the seafloor that was produced during the cruise of the research ship Kairei. Sissano Lagoon appears in the lower left comer. Note the convoluted course of the Yalingi submarine canyon. The sharp bends mark places where the canyon has been diverted by uplift of the seafloor by fault movements. The white lines mark the high-resolution seiemic reflection traverses. A strip of seafloor alng the coast, about 10 km across, remains unmapped because the water was too shallow for the safe operation of the ship.



TOKSAVE BILONG TSUNAMI

Tsunami em i wanem samting?

Tsunami o taidel weiv, em i tupela wod manmeri yusim long kolim bikpela si wantaim tait we i kamap long solwara. Dispela tsunami ken kamap taim bikpela guria tru save kamap aninit long solwara. Tsunami save kamap taim maunten-paia i pairap aninit long solwara. Na dispela pairap i strong tru na em i save brukim graun aninit long solwara.

Guria bilong tsunami em i strong moa yet. Em i save brukim ston na ol narapela strong-pela samting ol stap olsem banis long wokabaut bilong tsunami. Manmeri no mekim kamapim tsunami. Tsunami yet save kamap taim i gat bikpela seksek o guria aninit long solwara.

Hamas taim tsunami kamap pinis long Papua Niugini?

Insait long 100 yiar i go pinis, em i bin gat paipela-ten tsunami bin kamap long Papua Niugini. Planti bilong ol dispela tsunami no bikpela tumas. Ol i bin liklik, olsem na longpela bilong ol i bin inap tasol long wanpela o tupela mita.

Tsunami bilong bipo bin kilim manmeri?

Wanpela taidel weiv (tsunami) bin kamap long 1855 long hap bilong Rai Kos long Madang. Dispela tsunami bin kilim dai planti manmeri bilong wanpela pies long maus Wara Kabenau. Narapela taidel weiv i bin kamap long 1888 long Niubriten na hap bilong Siasi. Na em i bin kilim planti manmeri. Dispela tsunami, si bilong en i bin long-pela i go inap olsem 12pela mita.

Narapela taidel weiv i bin kamap long Buna long Oro Provins long yiar 1895. Dispela weiv i bin kilim dai tupela-ten-siks manmeri. Long yiar 1906 narapela weiv i bin kamap na kilim dai sampela manmeri long Gasmata long Wes Niubriten Provins. Na long 1930, narapela taidel weiv i bin kamap klostu long Bogia long Madang Provins na ol ailan bilong Ninigo long Manus Provins, na kilim dai 11-pela manmeri.

Tsunami kamap tu long ol narapela kantri?

0 brata .... askim bilong yu em i tru. Ol krismas i go pinis, planti kantri bilong Pasifik Ousen (Pacific Ocean), ol i bin kisim hevi long sampela tsunami. Na yu save olsem long Indonesia i bin gat tsunami long 1990, 1994 na 1996. I gat sampela manmeri we 1 bin dai long tsunami. Long 1996, tsunami bin kamap long Biak ailan long Irian Jaya, na em i bin kilim moa long wanhandet manmeri.

Na long Siapan, i gat bikpela wari long tsunami. Ol taidel weiv i bagarapim ol pies na ol fektri we i stap long nambis. Olsem na ol saintis bilong Siapan i wok yet long mekim wokpainaut long tsunami. Ol i laik save long laip, ran na pasin bilong tsunami. Tasol long halivim ol nau, ol i wok long mekim banis bilong lukautim ol taun na fektri long taidel weiv.

Sampela stori moa istap long beksait

«

TOKSAVE BILONG TSUNAMI

Bai yumi mekim wanem long halivim ol nambis manmeri bilong Papua Niugini?

Namba wan samting yumi olgeta i mas gat save long en pastaim, em long mak bilong tsunami long kamap. Ol dispela mak ol i toksave long yu long kamap bilong tsunami. Sapos yu stap long nambis o stap klostu long arere bilong solwara, yu na ol lainbilong

- yu i mas save gut long dispela tripela samting. Sapos:
- yu pilim graun i seksek o i guria, o
- yu lukim mak bilong solwara i go daun lusim mak bilong drai taim, o

yu harim nois olsem nois bilong smok-balus (jet balus),

yu na ol lain bilong yu i mas lusim pies kwiktaim tru. Ran i go long pies we solwara bilong tsunami no inap kisim yupela. Yumi kolim dispela kain pies long "seip pies".

Narapela gutpela we long halivim manmeri long abrusim bagarap bilong tsunami, em long planim planti strongpela diwai, olsem kalapulin na yar, long arere bilong nambis. Narapela samting bilong abrusim birua long tsunami, ol skul, hausik, paua haus, telepon haus na ol narapela kain samting we i ken pulim manmeri go long ol, ol i mas stap long pies we i "seip pies".

Seip pies em i olsem wanem?

Seip pies em i kain pies o hap we strongpela tait bilong solwara i no inap go long en. Em i kain pies we i stap abrus long ran bilong taidel weiv. Olsem na wanpela seip pies em long pies we i stap antap long maunten o long kil bilong maunten. Narapela seip pies em i stap 600 o 800 mita longwe long nambis. Sapos yu stap arere tru long nambis, yu mas ran 600 o 800 mita lusim nambis. Namba tri seip pies, em long go antap long strongpela diwai. Dispela namba tri seip pies i no gutpela tumas, tasol sapos yu no kisim toksave long tsunami na taidel weiv i kamap klostu tru long yu, yu mas go antap long strongpela diwai. Ol kokonas, kalapulin o yar i gutpela na strongpela diwai long go antap long ol.

Bilong wanem na i no bin gat toksave long dispela tsunami?

Sapos tsunami kamap long pies longwe olsem Saut Amerika o Alaska, bai gat bikpela taim long toksave. Toksave bilong taidel weiv bai kam kwik na olgeta bai ken redi long painim seip pies long stap. Tasol sapos tsunami stap klostu tru long pies yumi stap long en, dispela bai hat long salim toksave. Em bai no gat inap taim long toksave kwiktaim. Bikos long dispela kain taim, ol wanwan manmeri i mas tingling na luksave long mak o woning sain long kam bilong taidel weiv.

Sampela stori moa istap long insait

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